
A Biogeographic Assessment off North/Central California: To Support the Joint Management Plan Review for Cordell Bank, Gulf of the Farallones, and Monterey Bay National Marine Sanctuaries: Phase I - Marine Fishes, Birds and Mammals

**Prepared by NOAA's Center for Coastal Monitoring and Assessment - Biogeography Team
National Centers for Coastal Ocean Science**



Gulf of the Farallones National Marine Sanctuary



Dan Shapiro



Jan Roloff



Gulf of the Farallones National Marine Sanctuary



Cordell Bank Expedition

December 2003

ABOUT THIS DOCUMENT

In the spring of 2001, NOAA's National Marine Sanctuary Program (NMSP) and National Centers for Coastal Ocean Science (NCCOS), launched a 24-month effort to assess biogeographic patterns of selected marine species found within and adjacent to the boundaries of three west coast National Marine Sanctuaries. These sanctuaries, Monterey Bay, Gulf of the Farallones, and Cordell Bank, are conducting a joint review process to update sanctuary management plans. To support this review, NCCOS's Biogeography Program is leading a partnership effort to conduct a robust analytical assessment to define important biological areas and time periods within, and adjacent to, current sanctuary boundaries. The assessment was based on a synthesis of many data sets that were provided by project partners. This document represents the results of the first of two phases of the assessment. Phase I provides data, analytical results, a description of ecosystems and their linkages, identifies data gaps, and suggests future activities to be addressed in Phase II.

Phase I of the biogeographic assessment was formulated around three integrated study components: 1) an Ecological Linkages Report, 2) biogeographic analyses, and 3) development of Geographical Information System (GIS) data for incorporation into NMSP's Marine Information System (MarIS). The majority of the results from the assessment are presented as a suite of GIS maps to visually display species biogeographic patterns across the study area. The body of this document provides examples of the entire suite of digital map products found on the CD-ROM located on the back cover of this document. The spatial data and additional information, such as digital species distribution maps, and additional details on analytical methodologies are also presented on the CD-ROM. An HTML version of the CD-ROM can be found on the Biogeography Program website: http://biogeo.nos.noaa.gov/products/canms_cd/.

Results of the assessment are being used to assist the NMSP in addressing issues such as evaluating potential modification of sanctuary boundaries, and changes in management strategies or administration, based on the principles of biogeography. The progress of the biogeographic assessment for Central and Northern California National Marine Sanctuaries can be followed by consulting NCCOS's Biogeography Program web site: http://biogeo.nos.noaa.gov/projects/assess/ca_nms/. For questions and comments, please contact:

Dr. Mark E. Monaco, Biogeography Team Leader
NOAA/NCCOS/CCMA
1305 East West Highway, N/SCI1
Silver Spring, MD 20910
p. 301-713-3028 x 160
f. 301-713-4384
mark.monaco@noaa.gov

or

Mr. Charles E. Alexander, National Programs Branch Chief
NOAA/NMSP
1305 East West Highway,
Silver Spring, MD 20910
p. 301-713-3125 x 147
f. 301-713-0404
charles.alexander@noaa.gov

Project Team

David Ainley, H.T. Harvey and Associates
Satie Airamé, National Marine Sanctuary Program
Charles Alexander, National Marine Sanctuary Program
Lisa Ballance, Southwest Fisheries Science Center
Maria Brown, National Marine Sanctuary Program
Erica Burton, National Marine Sanctuary Program
Kenneth Buja, National Centers for Coastal Ocean Science
Chris Caldow, National Centers for Coastal Ocean Science
Janet Casey, R.G. Ford Consulting Company
John Christensen, National Centers for Coastal Ocean Science
Lawrence Claflin, National Centers for Coastal Ocean Science
Randall Clark, National Centers for Coastal Ocean Science
Michael Coyne, National Centers for Coastal Ocean Science
Andrew DeVogelaere, National Marine Sanctuary Program
William Douros, National Marine Sanctuary Program
R. Glenn Ford, R.G. Ford Consulting Company
Steve Gaines, University of California Santa Barbara
Tracy Gill, National Centers for Coastal Ocean Science
Jamison Higgins, National Centers for Coastal Ocean Science
Dan Howard, National Marine Sanctuary Program
Olaf Jensen, National Centers for Coastal Ocean Science
Carol Keiper, Oikonos
Matthew Kendall, National Centers for Coastal Ocean Science
Kevin McMahon, National Centers for Coastal Ocean Science
Mark Monaco, National Centers for Coastal Ocean Science
Wendy Morrison, National Centers for Coastal Ocean Science
Sean Morton, National Marine Sanctuary Program
Jan Roletto, National Marine Sanctuary Program
Larry Spear, H.T. Harvey and Associates
Lynn Takata, National Centers for Coastal Ocean Science
Mitchell Tartt, National Marine Sanctuary Program
Christine Taylor, National Marine Sanctuary Program
Ed Ueber, National Marine Sanctuary Program
Jeannette Waddell, National Centers for Coastal Ocean Science
Anne Walton, National Marine Sanctuary Program
Wendy Williams, R.G. Ford Consulting Co.

Citation:

NOAA National Centers for Coastal Ocean Science (NCCOS) 2003. A Biogeographic Assessment off North/Central California: To Support the Joint Management Plan Review for Cordell Bank, Gulf of the Farallones, and Monterey Bay National Marine Sanctuaries: Phase I - Marine Fishes, Birds and Mammals. Prepared by NCCOS's Biogeography Team in cooperation with the National Marine Sanctuary Program. Silver Spring, MD 145 pp.



Cover Photo by Kip Evans



TABLE OF CONTENTS

About This Document i

Table of Contents ii

Introduction..... 1

 The Study Area..... 1

 Study Objectives 1

Section 1 Synopsis of Ecological Linkages Report..... 6

 Introduction..... 6

 National Marine Sanctuaries of Central and Northern California 6

 Geographic Setting of the Study Area 6

 Ocean Currents 6

 Oceanographic Seasons 7

 Natural Perturbations 7

 Ecosystems 7

 Biogeography 8

 Conclusions 9

 References 9

Section 2 Biogeographic Analyses 10

 Introduction..... 10

 Assessment Process 10

 References 10

Section 2.1 Biogeography of Fishes..... 12

 Introduction..... 12

Subsection 2.1.1 Assemblage Analyses 13

 Introduction..... 13

 Review of Relevant Literature 13

 Introduction to Clustering 14

 Section Summary 33

 References 34

Subsection 2.1.2 Habitat Suitability Modeling 35

 Introduction..... 35

 Data and Analyses 35

 Analytical Map Products 36

 Section Summary 44

 Reviews 44

 Reviewers..... 44

 References 45

Section 2.2 Biogeography of Marine Birds 46

 Introduction..... 46

 Data and Analyses 46

 Analytical Map Products 50

 Section Summary 84

 Major Section Contributors..... 89

 Reviewers..... 89

 Personal Communications 89

 References 90

Section 2.3 Biogeography of Marine Mammals 92

 Introduction..... 92

 Data and Analyses 92

 Analytical Map Products 94

 Section Summary 123

 Discussion 125

 Major Section Contributors..... 125

 Reviewers..... 125

 Personal Communications 126

 References 126

Section 3 Integration of Analyses..... 129

 Introduction..... 129

 Data and Analyses 129

 Analytical Map Products 130

 References 136

Section 4 Data Sources and Gaps 138

 Introduction..... 138

 Conclusions and Recommendations for Future Activities 138

 References 139

Section 5 Summary of Biogeographic Assessment 140

 Background 140

 Biogeographic Assessment off North/Central California..... 140

 Ecological Linkages Report..... 140

 Biogeographic Analyses 141

 Integration of Analyses 142

 Data Sources and Gaps 143

 Phase II Biogeographic Assessment..... 143

 CD-ROM..... 143

 Concluding Comments 143

 References 143

Section 6 Phase II Biogeographic Assessment..... 144

Acknowledgments..... 145

List of Tables

Table 1. Site group results for recreational data. The numbers of trip/location combinations associated with each group as well as average depth, ± standard deviation, are provided. Different letters signify a significant difference using Tukey's pairwise comparison on log adjusted depth with overall alpha set at 0.001. 24

Table 2. Average frequency of occurrence of fish species assemblages (percent occurrence calculated for each species and then averaged for each fish assemblage) for each recreational site group. Numbers in bold represent influential species assemblages within that site group. 24

Table 3. Site group results for shelf trawl data. The numbers of trawls associated with each group as well as average depth ± standard deviation are provided. Different letters signify a significant difference using Tukey's pairwise comparison on log adjusted depth with overall alpha set at 0.001. 26

Table 4. Average frequency of occurrence of fish species assemblages (percent occurrence calculated for each species and then averaged for each fish assemblage) for each shelf site group. Numbers in bold represent influential species assemblages within that site group. 27

Table 5. Site group results for slope trawl data. The numbers of trawls associated with each group as well as average depth ± standard deviation are provided. Different letters signify a significant difference using Tukey's pairwise comparison on log adjusted depth with overall alpha set at 0.001. 28

Table 6. Average frequency of occurrence of fish species assemblages (percent occurrence calculated for each species and then averaged for each fish assemblage) for each slope site group. Bold numbers represent influential species assemblages within that site group..... 29

Table 7. Average frequency of occurrence of fish species assemblages (percent occurrence calculated for each species and then averaged for each fish assemblage) for each 1998 midwater site group. Number of trawls in each site group is provided in the first row. Bold numbers represent influential species assemblages within that site group..... 31

Table 8. Average frequency of occurrence of fish species assemblages (percent occurrence calculated for each species and then averaged for each fish assemblage) for each 1999 midwater site group. Number of trawls in each site group is provided in the first row. Bold numbers represent influential species assemblages within that site group..... 32

Table 9. Example data matrix for calculating bathymetry SI values for subadult bocaccio taken in NMFS trawl samples (Rubec et al., 1999). 36

Table 10. Example presence/absence information and SI calculation from scientific literature. 36

Table 11. Marine bird species used in this analysis..... 46

Table 12. Summary of at-sea survey data sets used in the analyses..... 47

Table 13. Summary of combined data set effort by ocean season. 48

Table 14. Assignment of warm, cold and neutral periods, based on surface water temperatures off Cental California 50

Table 15. Life history and management information for selected marine birds off north/central California. 84

Table 16. A summary of temporal and spatial patterns in the at-sea survey data (1980-2001) of selected marine birds off north/central California. 85

Table 17. Important at-sea areas for marine birds off north/central California, based on biomass, density and diversity.. 86

Table 18. Major marine bird colonies along the central California coast 87

Table 19. Three most important variables (of nine investigated) having independent effects in explaining the variance in density of 25 selected marine bird species. 88

Table 20. Effects of ocean season and ENSO events on the abundance of 26 marine bird species off central California between 1985 and 2002, as determined through multiple regression analyses.. 88

Table 21. A summary of changes in marine bird occurrence patterns, as a response to warm and cold ocean anomalies, as determined by visual comparison of species' maps during the 1997-1998 El Niño event and the 1999-2000 La Niña event..... 89

Table 22. Marine mammal species included in this assessment and map types developed for them (Phase I and Phase II) 92

Table 23. Summary of at-sea data sets used in the preliminary marine mammal analyses..... 93

Table 24. Summary of combined data set effort for mammals, by ocean season.. 93

Table 25. Preliminary life history and management information for selected marine mammals off north/central California.. 123

Table 26. Summary statistics and parameter estimates for spatial models. 130

Table 27. Matrix of data sets and their associated characteristics that were used or referenced in the biogeographic assessment. 138

List of Figures

Figure 1. Project flow diagram showing steps to complete Biogeographic Assessment Phase 1..... 1

Figure 2. Locator map of entire study area from Point Arena to Point Sal. National Marine Sanctuary boundaries shown in red. 2

Figure 3. Detailed locator map of northern study area from Bodega Head to Pescadero Point. National Marine Sanctuary boundaries shown in red..... 3

Figure 4. Detailed locator map of central study area from Pescadero Point to Pfeiffer Point. National Marine Sanctuary boundaries shown in red. 4

Figure 5. Detailed locator map of southern study area from Pfeiffer Point to Point Sal. National Marine Sanctuary boundaries shown in red. 5

Figure 6. Biogeographic assessment process 10

Figure 7. 3-D image of bathymetric relief within and adjacent to the sanctuaries 11

TABLE OF CONTENTS

Figure 8. Biogeographic approach to fish analysis 12

Figure 9. Hypothetical example of the methods used to determine species assemblages, site groups, and the interaction between species assemblages and site groups..... 15

Figure 10. Standard deviation of bathymetry calculated for a 1 km radius around each cell. Results are presented in standard deviations above or below the mean. 16

Figure 11. Species richness of individual NMFS shelf and slope trawls. 17

Figure 12. Mean species richness of NMFS shelf and slope trawls for 5' grid cells. The deviation is shown as an overlay to provide an indication of the variability in results for each grid cell. 18

Figure 13. Species diversity of individual NMFS shelf and slope trawls. 19

Figure 14. Mean species diversity of NMFS shelf and slope trawls for 5' grid cells. The deviation is shown as an overlay to provide an indication of the variability in results for each grid cell. 20

Figure 15. Species richness of rockfish from individual NMFS shelf and slope trawls.... 21

Figure 16. The relationship between depth and rockfish richness showing mean rockfish richness (for 10 meter depth intervals between 50-1,300 meters). The relationship was fit with a smoothing spline, lambda = 1,000,000. 21

Figure 17. NMFS shelf and slope trawls with the highest species diversity, species richness, and rockfish richness are mapped. The underlying map illustrates the bathymetric complexity of the study area and can be used to identify the shelf break. 22

Figure 18. Species assemblage results for the recreational data. Assemblages are named for the most influential species in each group. Assemblages are arranged from shallow to deep, unless they are influential at all or none of the depths. The assemblages that were not influential at any depth were composed of relatively rare species, making depth associations indiscernible given the methodology for defining "influential" assemblages. Non-italicized species were consistently placed into the same species assemblage >80% of the time; italicized species tended to roam into other assemblages with random sampling. 23

Figure 19. Location of CDF&G recreational fishing data in 2.5 minute grids which are color coded according to the average depth of the fishing trips within the grid cell. Lines showing the 50, 100, 200, and 2,000 depth contours are provided. 25

Figure 20. Species assemblage results for the shelf trawls. Assemblages are named for the most influential species in each group. Assemblages are arranged from shallow to deep, unless they are influential at all or none of the depths. The assemblages that were not influential at any depth were composed of relatively rare species, making depth associations indiscernible given the methodology for defining "influential" assemblages. Non-italicized species were consistently placed into the same species assemblage >80% of the time; italicized species tended to roam into other assemblages with random sampling. 26

Figure 21. Location of site groups for NMFS shelf trawls. Lines showing the 50, 100, 200, and 2,000 depth contours are provided. 27

Figure 22. Species assemblage results for the slope trawls. Assemblages are named for the most influential species in each group. Assemblages are arranged from shallow to deep, unless they are influential at all or none of the depths. The assemblages that were not influential at any depth were composed of relatively rare species, making depth associations indiscernible given the methodology for defining "influential" assemblages. Non-italicized species were consistently placed into the same species assemblage >80% of the time; italicized species tended to roam into other assemblages with random sampling..... 28

Figure 23. Location of site groups for NMFS slope trawls. Lines showing the 50, 100, 200 and 2,000 depth contours are provided. 29

Figure 24. Species assemblage results for the midwater trawls utilizing all data from 1986 to 2001. Assemblages are named for the most influential species in each group. Non-italicized species were consistently placed into the same species assemblage >80% of the time; italicized species tended to roam into other assemblages with random sampling..... 30

Figure 25. Species assemblage results for the midwater trawls conducted in 1998. Assemblages are named for the most influential species in each group. Non-italicized species were consistently placed into the same species assemblage >80% of the time; italicized species tended to roam into other assemblages with random sampling..... 31

Figure 26. Location of site groups for NMFS 1998 midwater trawls. Lines showing the 50, 100, 200, and 2,000 depth contours are provided. 31

Figure 27. Species assemblage results for the midwater trawls conducted in 1999. Assemblages are named for the most influential species in each group. Non-italicized species were consistently placed into the same species assemblage >80% of the time; italicized species tended to roam into other assemblages with random sampling..... 32

Figure 28. Location of site groups for NMFS 1999 midwater trawls. Lines showing the 50, 100, 200, and 2,000 depth contours are provided. 32

Figure 29. Overlap between the three data sets that analyzed demersal fish: CDF&G recreational (yellow), NMFS shelf (green), and NMFS slope (orange). 33

Figure 30. Species habitat suitability modeling approach. 35

Figure 31. Polynomial regression curve fit with mean log abundance by categorical bathymetric class for subadult bocaccio. 35

Figure 32. Bathymetric map for the north/central California study area. Red lines indicate National Marine Sanctuary boundaries. 37

Figure 33. Substrate types for the north/central California marine region. 38

Figure 34. Potential distribution of habitat suitability for adult and subadult bocaccio. Map inset contains validation statistics. SI values for bathymetry and substrate are graphically displayed below the map. 39

Figure 35. Potential distribution of habitat suitability for adult and subadult Dover sole. Map inset contains validation statistics. SI values for bathymetry and substrate are displayed below the maps. 40

Figure 36. Potential distribution of habitat suitability for adult dungeness crab. Map inset contains validation statistics. SI values for bathymetry and substrate are graphically displayed below the map. 41

Figure 37. Areas of groundfish potential hot spots based on mean fish species HSI models and overlap of predicted highly suitable habitats. 42

Figure 38. Areas of potential habitat importance based on mean HSI models for selected species assemblages. 43

Figure 39. Spatial extent of data sets used in the marine bird analysis: ship-based surveys. 47

Figure 40. Spatial extent of data sets used in the analysis: aerial surveys. 48

Figure 41. Total survey effort for marine bird analyses..... 49

Figure 42. Western and Clark's grebes, seasonal density and high use areas..... 51

Figure 43. Northern fulmar, seasonal density and high use areas. 53

Figure 44. Sooty shearwater, seasonal density and high use areas. 55

Figure 45. Ashy storm-petrel, seasonal density, high use areas, and breeding colonies.57

Figure 46. Leach's storm-petrel, seasonal density, high use areas, and breeding colonies..... 59

Figure 47. Scoters, seasonal density and high use areas..... 61

Figure 48. Brown pelican, seasonal density and high use areas. 63

Figure 49. Black-legged kittiwake, seasonal density and high use areas. 65

Figure 50. Common murre, seasonal density, high use areas and breeding colonies. . 67

Figure 51. Rhinoceros auklet, seasonal density, high use areas and breeding colonies. 69

Figure 52. Marine bird density, by season and for all seasons..... 71

Figure 53. Marine bird biomass, by season and for all seasons. 72

Figure 54. Marine bird diversity, by season and for all seasons..... 73

Figure 55. Major marine bird breeding colonies. 75

Figure 56. Density in warm, cold, and neutral periods: 1980-2001. 76

Figure 57. Biomass in warm, cold and neutral periods: 1980-2001. 78

Figure 58. Diversity in warm, cold and neutral periods: 1980-2001. 80

Figure 59. Density during El Niño and La Niña events, 1997-2000. 82

Figure 60. El Niño/La Niña Event changes, as an example of regime shift effects..... 83

Figure 61. Total at-sea survey effort for marine mammal analysis. 94

Figure 62. Maps for southern sea otter: rangewide count and linear density, fall 2001 and spring 2002. 95

Figure 63. Map for California sea lion: haulouts and rookeries. 96

Figure 64. Maps for California sea lion: seasonal at-sea densities, high use areas and rookeries. 97

Figure 65. Map for Steller sea lion: at-sea sightings and survey effort, rookeries and haulouts..... 99

Figure 66. Maps for northern fur seal: seasonal at-sea densities, high use areas and rookery. 101

Figure 67. Map for harbor seal: at-sea sightings, survey effort and haulouts..... 103

Figure 68. Map for northern elephant seal: at-sea sightings and survey effort, rookeries and haulouts..... 105

Figure 69. Maps for Dall's porpoise: seasonal at-sea densities and high use areas..... 107

Figure 70. Maps for Pacific white-sided dolphin: seasonal at-sea densities and high use areas. 109

Figure 71. Maps for Risso's dolphin: seasonal at-sea densities and high use areas..... 111

Figure 72. Maps for northern right-whale dolphin: seasonal at-sea densities and high use areas. 113

Figure 73. Map for blue whale: at-sea sightings and survey effort..... 115

Figure 74. Maps for humpback whale: seasonal at-sea densities and high use areas. 117

Figure 75. Maps for gray whale: seasonal at-sea densities and high use areas..... 119

Figure 76. Maps for Dall's porpoise: SWFSC stock assessment data: average group size of sightings and survey effort..... 121

Figure 77. Maps for blue whale: SWFSC stock assessment data: average group size of sightings and survey effort..... 122

Figure 78. Maps for humpback whale: SWFSC stock assessment data: average group size of sightings and survey effort..... 122

Figure 79. Pictogram of species diversity. 129

Figure 80. Estimated diversity (a), density (b), and hot spots (top 20%) (c) for marine birds. 131

Figure 81. Relationships between bird diversity and bathymetric variance and between bird density and depth. 131

Figure 82. Estimated diversity (a), density (b), and hot spots (top 20%) (c) for fish..... 132

Figure 83. Integration option 1, diversity hot spots (top 20%) for fish and marine birds. Coastal kelp bed areas are also shown. 133

Figure 84. Integration option 2, density hot spots (top 20%) for marine birds and fish. Coastal kelp bed areas are also shown. 134

Figure 85. Integration option 3, diversity and density, hot spots (top 20%) for fish and marine birds. Coastal kelp bed areas are also shown. 135

INTRODUCTION

In the spring of 2001, NOAA's National Marine Sanctuary Program (NMSP) and National Centers for Coastal Ocean Science (NCCOS), in consultation with the National Marine Fisheries Service (NMFS), launched a 24-month effort to define and assess biogeographic patterns of selected marine species found within and adjacent to the boundaries of three west coast National Marine Sanctuaries. These sanctuaries, Monterey Bay, Gulf of the Farallones, and Cordell Bank are conducting a joint review process to update sanctuary management plans. The management plans for these sanctuaries have not been updated for over ten years and the status of the natural resources and their management issues in and around the sanctuaries may have changed. In addition, significant accomplishments in research and resource assessments have been made within the region. Thus, it is important to incorporate new and expanding knowledge into the revised management plans for these Sanctuaries.

As part of the review process, the NMSP requires an integrated biogeographic assessment of the spatial and temporal distributions of marine resources off north/central California. The NMSP headquarters and sanctuary field personnel have partnered with NCCOS's Biogeography Team to conduct this assessment. The biogeographic assessment includes the identification and characterization of important biological areas and time periods off the coast and addresses existing and emerging issues concerning management of biotic resources in the area. Results of this assessment aid the NMSP in addressing issues, such as potential modification of sanctuary boundaries and changes in management approaches based on the principles of biogeography. The publication of this document completes Phase I of the biogeographic assessment for the North/Central California National Marine Sanctuaries. The assessment and additional ecosystem characterization of habitats and species (e.g., estuaries) will continue over the next few years. The initial plans for Phase II are discussed in Section 6 of this document.

The Phase I assessment is based on biogeographic patterns of fishes, macroinvertebrates, marine mammals, and marine birds and the distribution of their habitats. The study did not attempt to define biogeographic patterns along the entire US west coast nor in very near shore environments (e.g, estuaries). Rather, the study area was restricted to the marine area from Point Arena (in the north) to Point Sal, California (in the south). The Assessment was based on a synthesis of data provided by project partners (e.g., NMFS fishery independent surveys). The biogeographic assessment was formulated around three integrated study components: 1) an *Ecological Linkages Report*, 2) biogeographic analyses, and 3) development of spatial data for incorporation into NMSP's Marine Information System (MarIS). GIS-based data and additional information, such as the complete *Ecological Linkages Report*, can be found on the

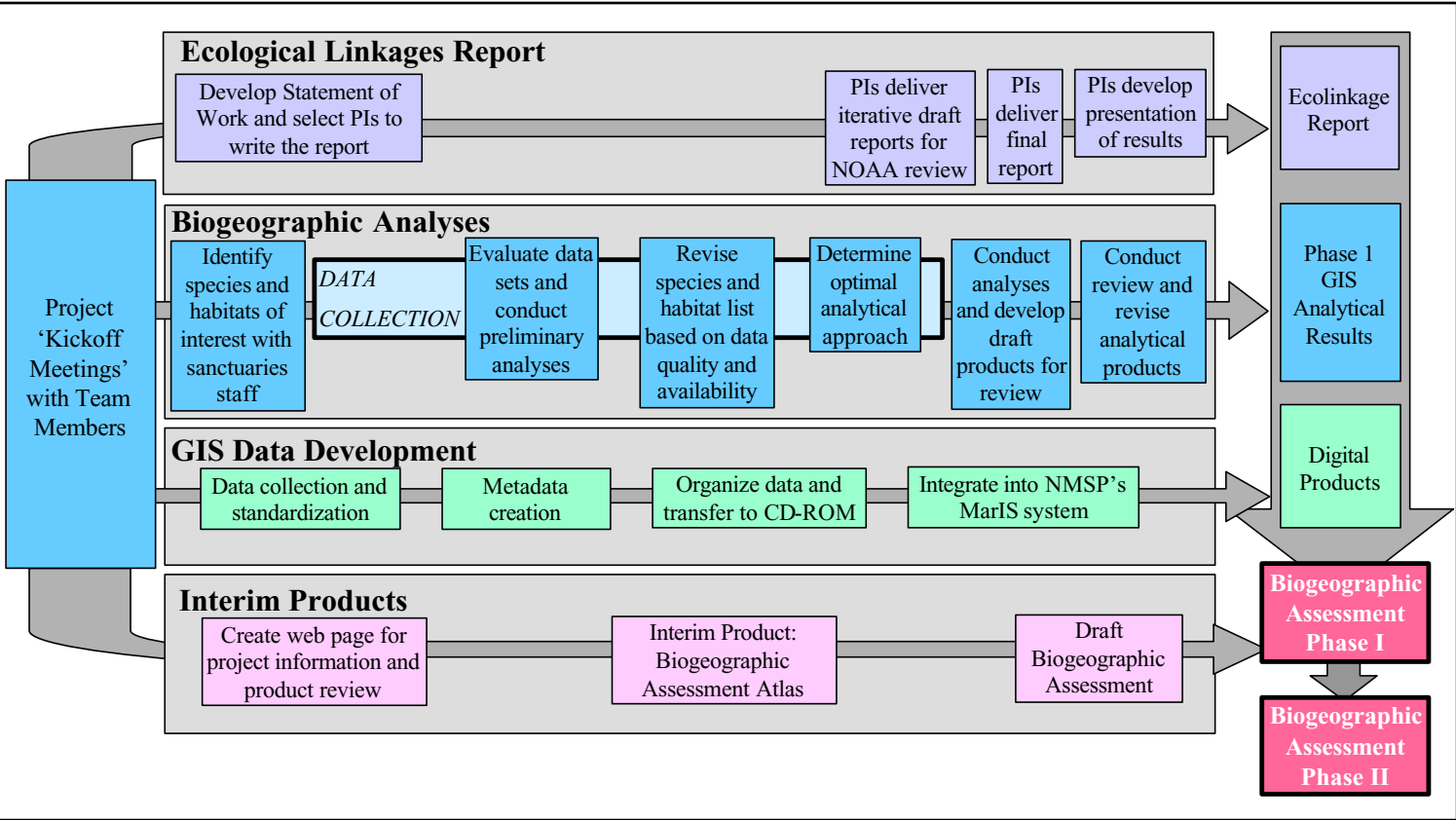


Figure 1. Project flow diagram showing steps to complete Biogeographic Assessment Phase 1.

CD-ROM on the back cover of this document. To enable development and integration of these components and to support project management, the overall process used to conduct the biogeographic assessment is shown in Figure 1.

The *Ecological Linkages Report* is a comprehensive synthesis of existing information on ecological relationships between marine biota and the habitats they utilize along the West Coast. The report is much broader in geographic scope than the project study area and provides the context to understand overall assessment results relative to the biogeography of the West Coast. In addition, the report addresses near-shore and estuarine ecosystems while quantitative data analyses were conducted only for the marine waters of the National Marine Sanctuaries.

The biogeographic analyses component includes a suite of quantitative spatial and statistical analyses based on the distribution and abundance of fishes, marine birds, and marine mammals found in the Point Arena to Point Sal study area. The analytical results contributed to defining important biological areas throughout the region, based on visualization of species distribution patterns and community metrics. The results aid in

understanding the potential implications to changes in sanctuary boundaries or management strategies relative to marine biogeography within and adjacent to the sanctuaries.

To enable NMSP and others to make maximum use of the spatial data generated from this study and other activities that are supporting the joint management plan revision process (e.g., economic assessments), the NMSP is developing a GIS tool. This GIS tool, the Marine Assessment and Resource Information System (MarIS), has been designed to facilitate the organization and analysis of spatial data to support NMSP management questions and issues within and across the sanctuaries. All GIS compatible data, the *Ecological Linkages Report*, and products from the biogeographic analyses component are found on the companion CD-ROM. The contents of the CD-ROM are also found on the web at http://biogeo.nos.noaa.gov/products/canms_cd/. All of the applicable digital data will be integrated into MarIS.

THE STUDY AREA

The study area, shown on the locator maps, extends from Point Arena, in the southern portion of Mendocino county, to Point Sal, just south of Pismo Beach and the Nipomo Dunes area in

Northern Santa Barbara county (Figure 2). Based on the California Department of Fish and Game's 200-meter resolution bathymetry data, this map displays the locations of prominent bathymetric features occurring off the coast, including the continental shelf/slope interface. In support of this assessment, the National Geophysical Data Center, Monterey Bay Aquarium Research Institute, and the NMSP jointly developed the first high-resolution 70-meter bathymetry maps for the region. The highly resolved bathymetry is shown on the three regional maps to highlight the complexity of the seafloor and to begin outlining the multitude of distinct ecosystems occurring in this region (Figures 3-5). The Northern Region map focuses on Cordell Bank and Gulf of the Farallones National Marine Sanctuaries. Cordell Bank, the Farallon Islands, Bodega and Pioneer Canyons, and Gumdrops and Pioneer Seamounts appear as very clear features along the seafloor. The focus of the Central Region map is Monterey Bay. The most significant feature in this regional view is the Monterey Canyon, although the nearby canyons, Ascension, Año Nuevo, Cabrillo, Soquel, and Carmel, are also labeled. Other significant bathymetric features in this region include the Guide Seamount, Sur Ridge, and Shepard Meander. The bathymetry for most of the Southern Region map is less resolved than the other two, as the frequency of sampling was significantly less. In this area, the Sur and Lucia Canyons are found, as well as Santa Lucia Bank and one of the most prominent features in this region, the Davidson Seamount. Descriptions of the features observed in these maps, along with the linkages and processes operating to influence the distribution of associated biota, are found in the *Ecological Linkages Report*.

STUDY OBJECTIVES

Based on consultations with NMSP field and headquarters staff and requirements to update the sanctuary management plans, the following study objectives were addressed:

1. Identify and compile available priority biological and environmental data sets in the study area in order to conduct biogeographic analyses.
2. Conduct marine biogeographic analyses of available data to define significant biological areas (i.e., "hot spots") and time periods, based on species distributions, abundance, habitats, life stage function, and community metrics (e.g., species richness, diversity).
3. Produce a report that describes the ecological components and linkages between the estuarine, coastal, and marine ecosystems of north/central California.
4. Develop GIS compatible data for integration into the NMSP's Marine Information System (MarIS) to support

INTRODUCTION

sanctuary staff in developing and evaluating resource management scenarios.

5. Support sanctuary staff in the integration of biogeographic assessment products into revisions of the sanctuary management plans.

The publication of this product completes Phase I efforts to meet objectives 1-4. The data and analytical results from these objectives will be used to address objective 5 over the next year. This investigation synthesized many databases and information sources for the study area. The data and information originated from a wide variety of government, academic, and private institution studies that had different objectives, study areas, and methodologies. Thus, several criteria were used in selecting appropriate data sets for biogeographic analyses. For example, the selection process favored databases that addressed the entire study area and were conducted relatively consistently over time. Thus, small databases that were limited in both content and spatial coverage were generally not useful in developing the assessment. When appropriate, these types of databases were used to aid in the interpretation of results and to develop and validate species habitat suitability models.

The following sections of this document provide information on the data compiled, analytical approaches, and Phase I assessment results. For the three main study components, (the *Ecological Linkages Report*, biogeographic analyses, and the CD-ROM contents), the primary information found within each component is introduced, methods described, and representative or example results provided. Many of the results are presented as map products to easily convey the biogeographic distribution of species and associated habitats. In addition, a summary of the biogeographic assessment is found in section 5. For more complete information (e.g., complete suite of digital species maps), please review and use the digital contents of the CD-ROM or the web version at http://biogeo.nos.noaa.gov/products/canms_cd/.

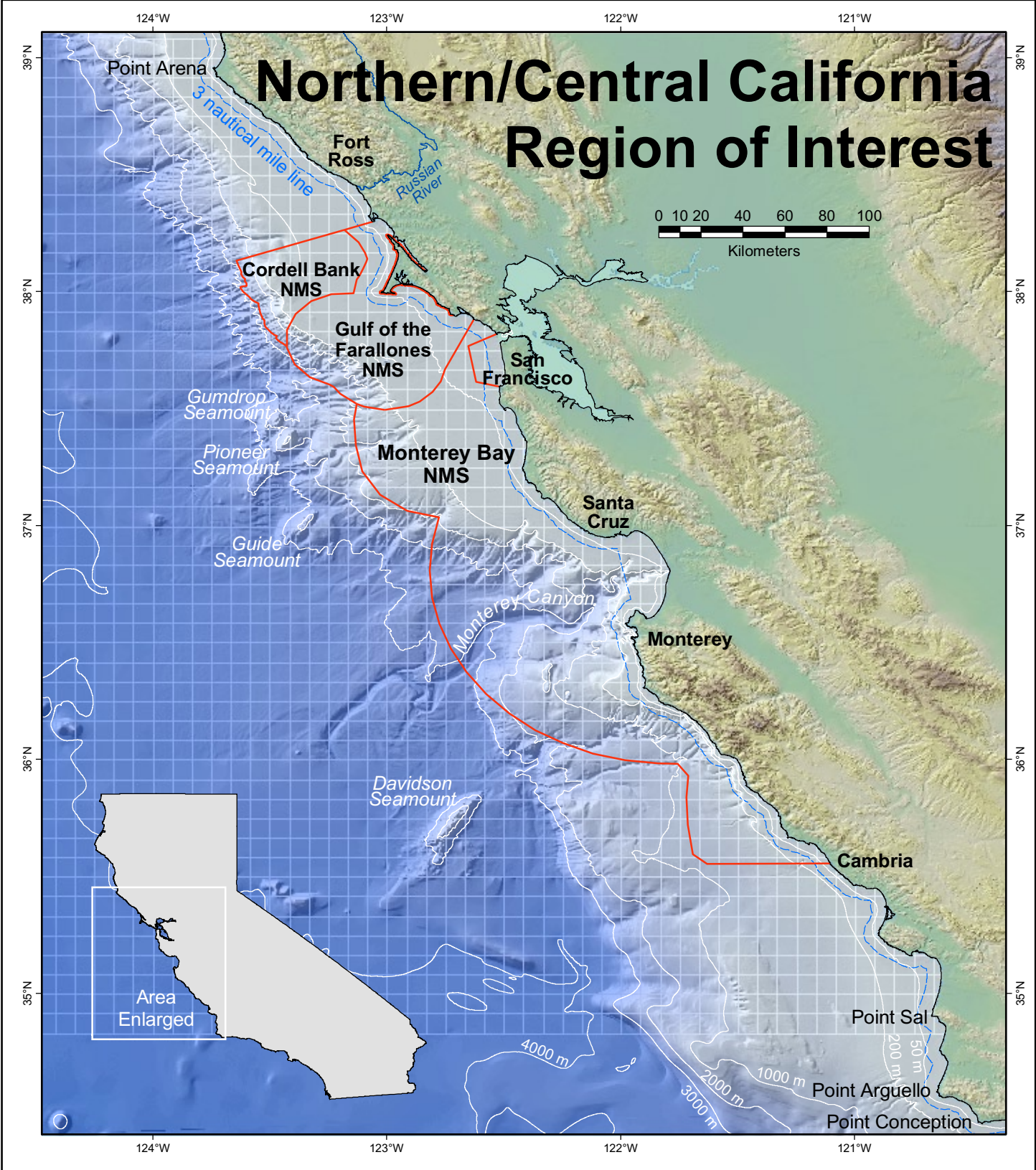


Figure 2. Locator map of entire study area from Point Arena to Point Sal. National Marine Sanctuary boundaries shown in red.

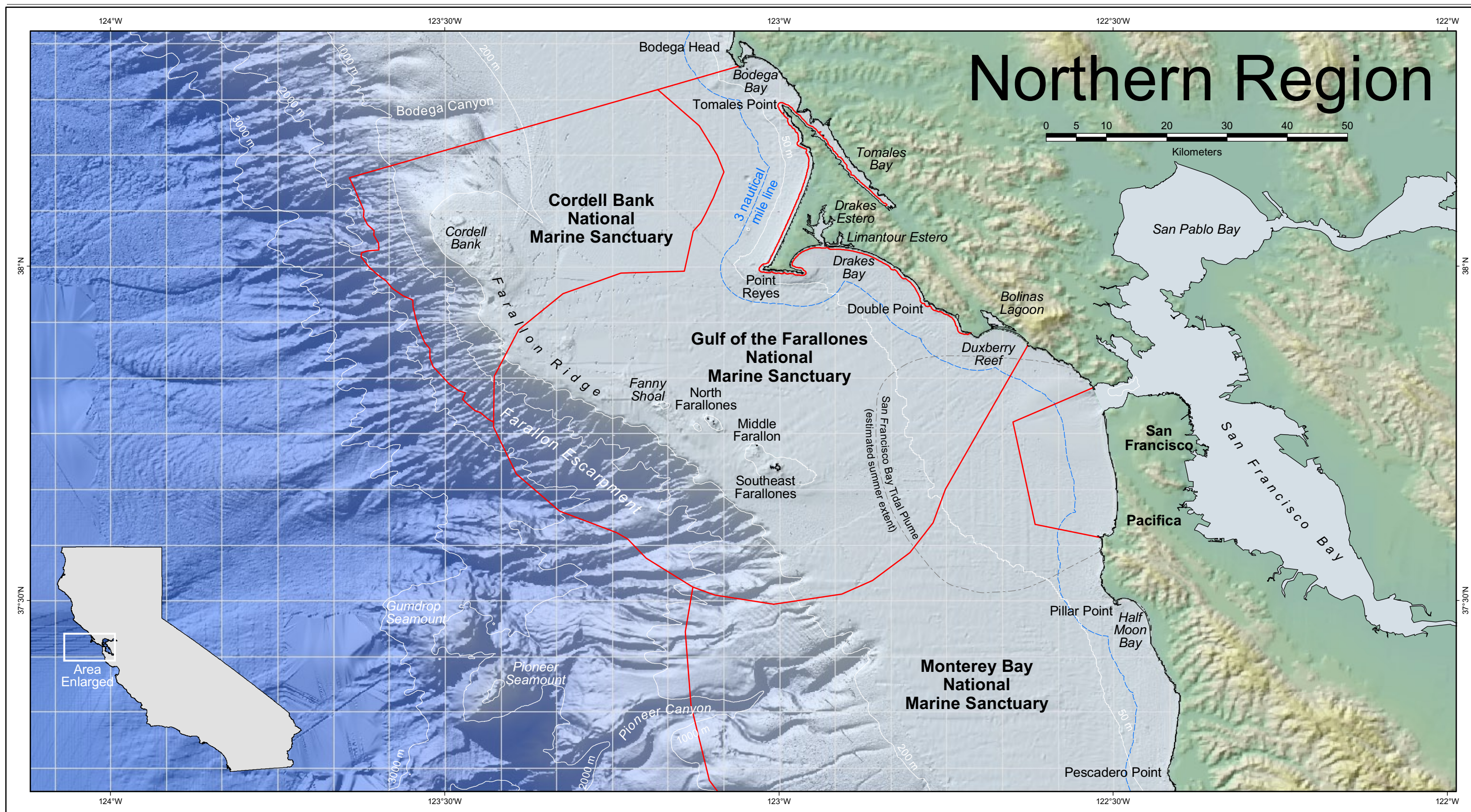


Figure 3. Detailed locator map of northern study area from Bodega Head to Pescadero Point. National Marine Sanctuary boundaries shown in red.

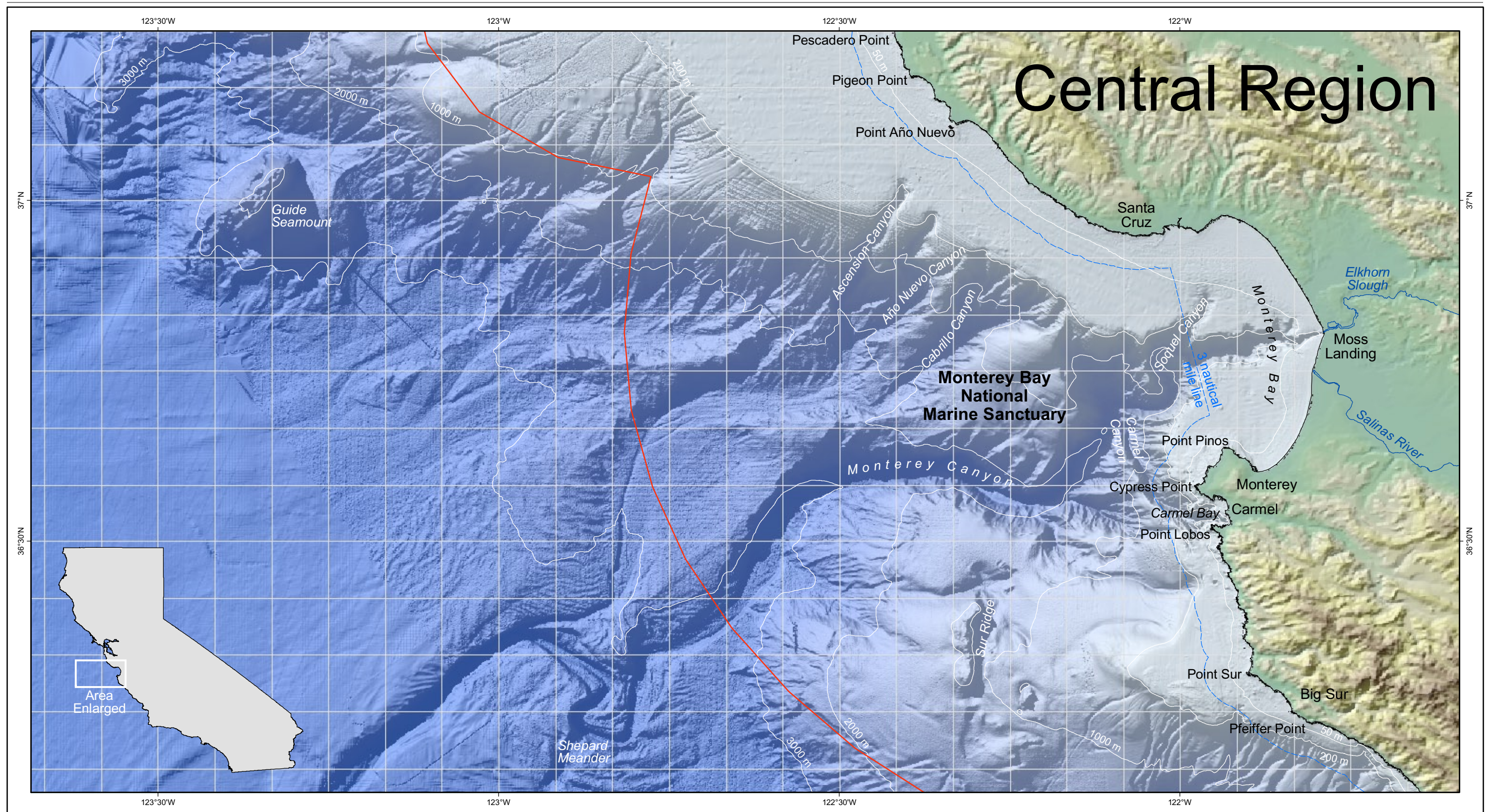


Figure 4. Detailed locator map of central study area from Pescadero Point to Pfeiffer Point. National Marine Sanctuary boundaries shown in red.

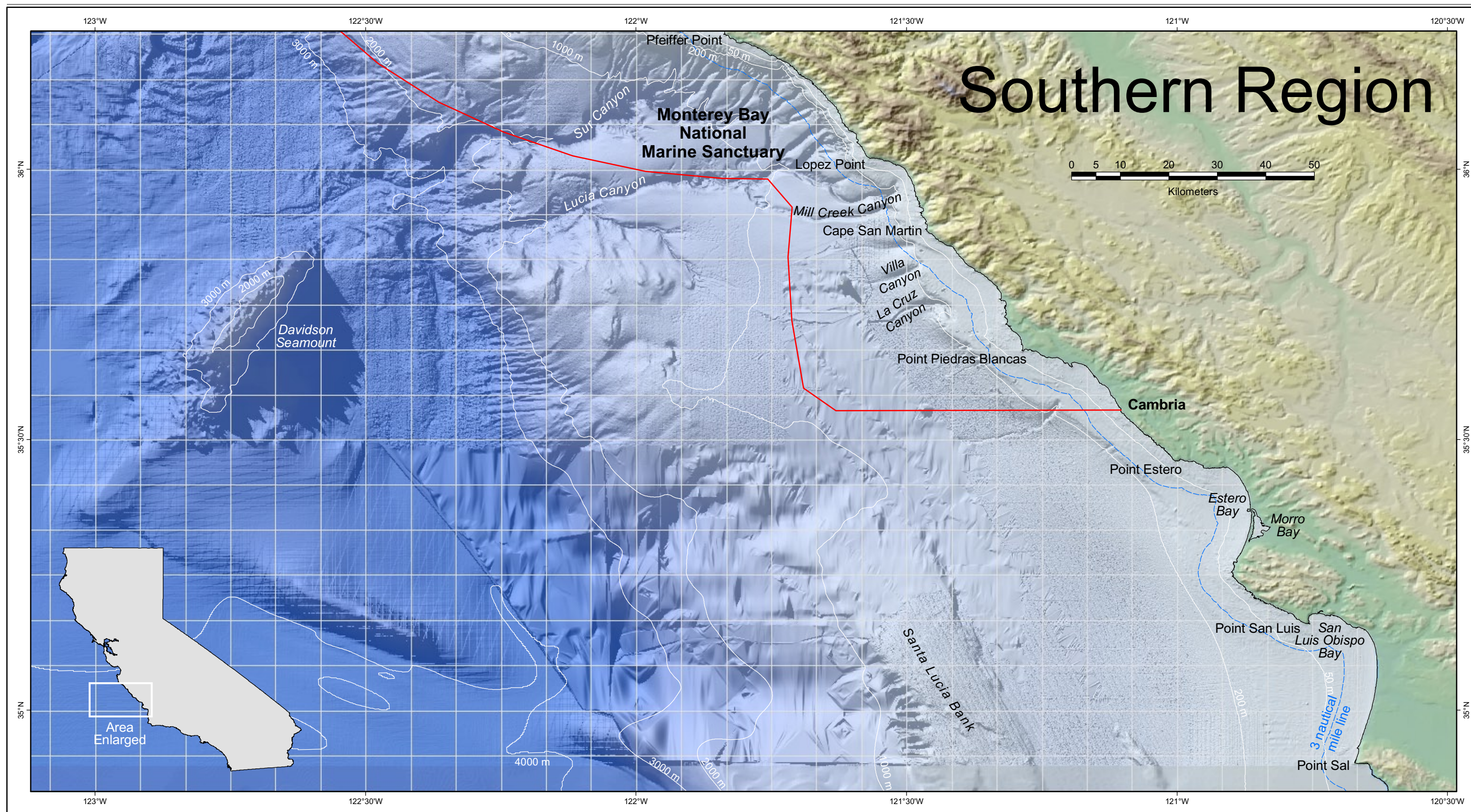


Figure 5. Detailed locator map of southern study area from Pfeiffer Point to Point Sal. National Marine Sanctuary boundaries shown in red.

Section 1: SYNOPSIS OF ECOLOGICAL LINKAGES REPORT

INTRODUCTION

The Ecological Linkages Report complements the biogeographic analyses conducted by The National Centers for Coastal Ocean Science (NCCOS) by providing an overview of the physical and biological characteristics of the region. Key ecosystems and species occurring in estuarine and marine waters off northern and central California are highlighted and linkages between them discussed. In addition, this report describes biogeographic processes operating to affect species' distributional patterns. The biogeographic analyses build upon this background to further understanding of the biogeography of this region. The following material is a synopsis of the report either excerpted or directly summarized from the completed document (Airamé et al., 2003) found on the companion CD-ROM.

NATIONAL MARINE SANCTUARIES OFF CENTRAL AND NORTHERN CALIFORNIA

The study area, from Point Arena to Point Sal, includes three national marine sanctuaries (Cordell Bank, Gulf of the Farallones, and Monterey Bay) encompassing marine and estuarine habitats along the central and northern coast of California. Together, these contiguous national marine sanctuaries include more than 650 km of coastline, from Bodega Bay, north of San Francisco, to Cambria, near San Luis Obispo, and a total area of approximately 18,000 km².

The Gulf of the Farallones National Marine Sanctuary, established in 1981, includes an area of 3,250 km² off the northern and central California coast. The Gulf of the Farallones extends beyond the Sanctuary's boundaries and is one of the broadest sections of the continental shelf off the U.S. West Coast. Besides the broad shelf, the major oceanographic feature that affects this coastal region is the San Francisco Bay Plume, which, under certain conditions, extends outwards to all areas of the Gulf. The Golden Gate, from which the plume emanates, lies midway along this section of coast. The Gulf of the Farallones National Marine Sanctuary itself, however, extends along the coast only as far south as Rocky Point, Marin County (where the Gulf of the Farallones National Marine Sanctuary abuts the Monterey Bay National Marine Sanctuary). Offshore, the Gulf of the Farallones National Marine Sanctuary extends farther south to the waters west of San Mateo County. Habitats within the Gulf of the Farallones National Marine Sanctuary include rocky shores, sandy beaches, estuaries, lagoons and bays, as well as the Farallon Islands and the subsurface Farallon Ridge. The entire stretch of the broad shelf within the physical features described above is strongly influenced by coastal upwelling and the San Francisco Bay Plume. The upwelled waters, which support tremendous phytoplankton production, are advected offshore into the California Current as eddies and jets. These productive waters stimulate growth of organisms



Dan Richards

at all levels of the marine food web. In periods when upwelling is reduced, the nutrient input from the San Francisco Plume becomes important. The Farallon Islands, which are protected as a National Wildlife Refuge, are home to the largest concentration of breeding seabirds in the contiguous United States (12 species), as well as one of the richest assemblages of pinnipeds (5 species). About 163 species of marine, coastal, and estuarine birds and 36 species of marine mammals use the Sanctuary during breeding or migration. Further, great white sharks are attracted to marine mammal colonies on the Farallon Islands, Point Año Nuevo, and Año Nuevo Island.

The Cordell Bank National Marine Sanctuary, designated in May 1989, includes an area of 1,362 km² off the coast of central California (*Figure 2: Northern Region*). Cordell Bank is located at the edge of the continental shelf, about 80 km northwest of the Golden Gate Bridge and 33 km west of Point Reyes. The main feature of the Sanctuary is an offshore granite bank, 7 km wide and 15 km long. The rocky bank emerges from the soft sediments of the continental shelf, reaching within 37 m of the

ocean's surface. The base of the Bank is over 120 m deep. The combination of oceanographic conditions and undersea topography of Cordell Bank supports a diverse and productive marine ecosystem. A persistent upwelling plume projects southward and offshore from Point Arena and Point Reyes, transporting nutrients and organisms suspended in the water column into the bank's relatively shallow waters. Insolation fuels primary productivity and eventually influences the entire food web through direct and indirect trophic linkages. This high local productivity supports abundant resident populations of invertebrates, fishes (240 species), seabirds (69 species), and marine mammals (28 species), and attracts many migratory species.

The Monterey Bay National Marine Sanctuary, established in 1992, is the largest of 13 marine sanctuaries administered by the National Marine Sanctuary Program. The Sanctuary extends from Rocky Point to Cambria Rock, encompassing nearly 450 km of shoreline and 13,780 km² of ocean, extending an average distance of 32 km from shore. At its deepest point, the Sanctuary reaches a depth of 3,250 m. The Sanctuary includes

a variety of coastal and marine habitats, such as rugged rocky shores, lush kelp forests, and several underwater canyons, the largest of which is the Monterey Submarine Canyon. North of Partington Point and within the Gulf of the Farallones, the continental shelf is relatively wide and shallow. South of Partington Point, the Sanctuary generally protects deep ocean, owing to the consistently narrow continental shelf that extends south to Point Conception. The diverse array of habitats in the Sanctuary is home to 33 marine mammals, 94 species of seabirds, at least 345 species of fishes, and numerous invertebrates, and plants.

GEOGRAPHIC SETTING OF THE STUDY AREA

The study region extends from Point Arena, a small peninsula on an elevated coastal plain in the southern portion of Mendocino County, to Point Sal, just south of Pismo Beach and the Nipomo Dunes area. The region consists of a multitude of diverse and important ecosystems that are very unique in their assemblages of marine organisms. Beginning near-shore, the coast of California, especially north of Point Reyes and south of Point Pinos, is renowned for its strikingly beautiful, dramatic rocky cliffs. Pocket beaches occur along the coast where streams and rivers deposit sediment along the shore. Rivers that flow over broad, flat expanses of soft sediments into the ocean may be strongly influenced by tides and are frequently associated with upland and salt marshes, sandy beaches, intertidal flats, and estuaries. Estuaries and lagoons commonly form where rivers enter the ocean, mixing fresh and salt water. Rocky shores, which are more resistant to erosion than the sandy beaches, support a complex intertidal community, influenced primarily by the semidiurnal movements of tides. Moving offshore, subtidal communities are strongly influenced by sediment type, nutrient input, and depth. The majority of the continental shelf is sandy, but rocky outcrops cover a portion of it, forming submerged reefs, seamounts, and other features. Marine algae, unable to attach to the shifting sandy sediments, find more secure substrate on rocky reefs. At the shelf break, the continental slope drops precipitously to depths of over 3000 m. Sediments, transported down the continental slope and submarine canyons, collect in broad fans at the base of the slope. Below the rise, the abyssal plain is relatively flat, broken occasionally by such features as seamounts and small depressions. It is this array of ecosystems, combined with the oceanographic processes affecting the composition and abundance of marine organisms in them, that make this such a unique area.

OCEAN CURRENTS

The cold water California Current and comparatively warm-water Davidson Currents are major forces shaping the ecosystems in and around the study region. They affect upwelling and downwelling and, consequently, the amount of productivity

Section 1: SYNOPSIS OF ECOLOGICAL LINKAGES REPORT



seen along the coast. Additionally, where the two converge at Point Conception, a barrier is created that many species do not cross. The species north of Point Conception, encompassing the entire study region right up through Washington State, are a part of the Oregonian Province, while just south of Point Conception, they belong to the Californian Province. Although many species have ranges that end at the borders of these biogeographic zones under normal conditions, species of the subtropical Californian Province may occasionally extend their ranges to central and northern California during unusually warm oceanographic events, such as El Niño and the Pacific Decadal Oscillation. Other more localized oceanographic features, such as eddies, internal waves and bores, are also important factors influencing the distribution and abundance of marine species.

OCEANOGRAPHIC SEASONS

While certain geological and biological features are evident along particular regions of the coast, the same oceanographic processes and climatic phenomena are operating throughout

the study region. Over a 12 month time-frame, the study area is exposed to three distinct oceanographic periods that vary with respect to prominence and location of ocean currents. These periods, described by upwelling (March to August), wind relaxation (August to November), and winter storms (November to March), are associated with different degrees of upwelling or downwelling. The amount of production in surface waters and the ability of organisms to disperse is directly impacted by these processes. In response to these periods, the abundance and types of organisms present in a given region change throughout the year.

NATURAL PERTURBATIONS

Longer term climatic phenomena influencing the region include: El Niño, Pacific Decadal Oscillation, and global warming. Off the coast of California, El Niño events are characterized by increases in ocean temperature and sea level, enhanced on-shore and northward flow, and reduced coastal upwelling of deep, cold, nutrient-rich water. During this period, survivorship and reproductive success of planktivorous invertebrates and

fishes decrease with plankton abundance. Marine mammals and seabirds, which depend on these organisms for food, suffer food shortages, leading to widespread starvation and decreased reproductive success.

Every 20-30 years, the surface waters of the central and northern Pacific Ocean shift several degrees from the mean temperature. Such shifts in mean surface water temperature, known as the Pacific Decadal Oscillation, have been detected 5 times during the past century, with the most recent shift in 1998. The Pacific Decadal Oscillation impacts production in the eastern Pacific Ocean and, consequently, affects organism abundance and distribution throughout the food chain.

Ocean waters off the coast of California have warmed considerably over the last 40 years. It is not yet clear if this warming is a consequence of an interdecadal climate shift or global warming.

In response to these three phenomena, some species have shifted their geographic ranges northward, altering the composition of local assemblages.

ECOSYSTEMS

The Land-Sea Interface

Rivers carry freshwater and sediments to bays, estuaries, and the ocean. Thirteen major watersheds are located along the central California coast. Historically, these supported large numbers of coho and chinook salmon, steelhead trout, and sturgeon. Today, many native anadromous fish stocks throughout California are in danger of extinction. General degradation of upland watershed and freshwater ecosystems is a major factor in the decline.

Two major estuaries in northern and central California are San Francisco Bay and Tomales Bay. Several smaller estuaries and lagoons within the region, from north to south, are Estero Americano, Estero de San Antonio, Bolinas Lagoon, Drakes/Limantour Estero, and Elkhorn Slough (National Estuarine Reserve). Estuaries and bays are vulnerable to coastal development, pollution, introduction of invasive species, and commercial and recreational fishing for species that live in near-shore waters. Humans have modified and transformed about 90% of the wetlands in California. The existence and health of these coastal wetlands is critical to the survival of organisms that depend on these habitats for survival. One of California's wetland sites, Bolinas Lagoon, was designated as internationally important in this role under the Convention on Wetlands, signed in Ramsar, Iran in 1971.

Wetlands along the central California coast are sparse, but those present support millions of shorebirds and waterfowl dur-

ing spring and fall migrations and the winter months. Migratory species require consistent sources of food and shelter along their migration route. If the distances between wetlands are too large, migrating birds may become exhausted and disoriented, increasing mortality.

Numerous marine species use embayments, lagoons, and estuaries as spawning and nursery grounds. Bat rays, leopard and smoothhound sharks, midshipman, Pacific herring, starry flounder, staghorn sculpin, surf perch of several species, jacksmelt, topsmelt, and pile perch mate and bear their young in estuarine habitats. Shallow, coastal waters of central and northern California also are critical habitat for chinook and, especially, coho salmon as they travel *en route* to spawning grounds in autumn and winter.

Geology and other physical forces influence the structure of the coastline. Energetic forces of water and wind erode the rocky coastline, creating the dramatic rocky intertidal habitat characteristic of the northern and central California coast. Small beaches form along the northern California coast where wind and waves erode granite and basalt cliffs. Further south, erosion of soft shale and sandstone bluffs creates the broad sandy beaches typical of southern California.

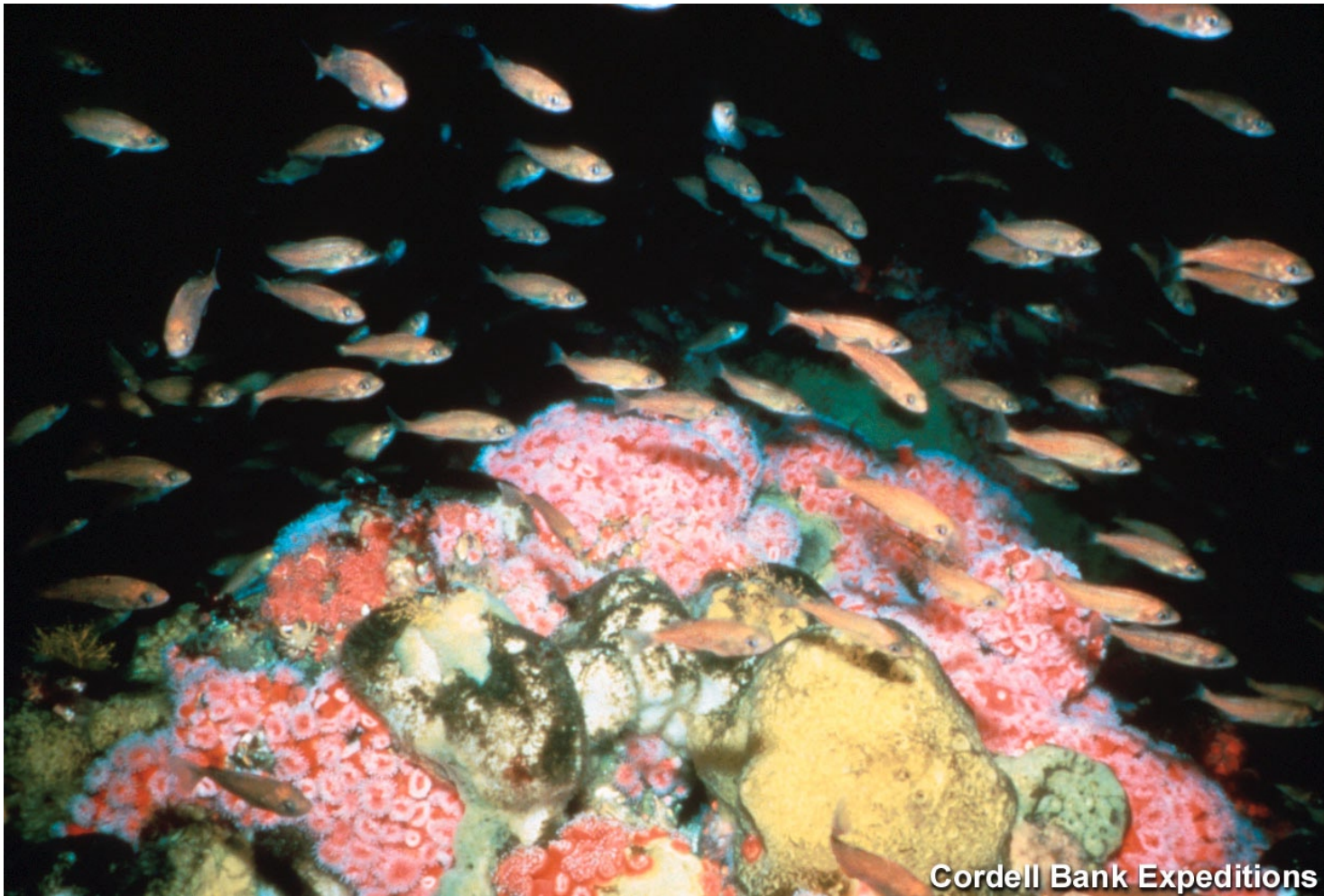
Sandy beach and rocky intertidal habitats are divided into distinct biological zones relative to height above mean high tide. In part, species' distributions are affected by their physiological tolerance to temperature, moisture, and salt. In response to these and other physical factors, the number of species of marine algae, gastropods, and fishes increases with depth in the intertidal zone.

Nutrients processed in marine systems are essential to communities using sandy beaches and rocky intertidal habitat. Waves carry and deposit plankton, macroalgae, as well as occasional corpses of fishes, birds, and marine mammals in the intertidal zone, which provide an unpredictable and patchy source of food. Beach wrack attracts numerous mobile organisms, including amphipods, isopods, flies, beetles, and shorebirds. The sporadic deposition of food from the ocean sustains intertidal communities in habitats that are subjected to strong physical forces and relatively low local production.

Marine Ecosystems

Production in subtidal habitats depends on levels of light and nutrients, and exposure to physical forces. Sufficient light to support highly productive photosynthetic communities penetrates surface waters to approximately 30 m. Kelp, which can grow up to 10 cm per day, is among the most productive of marine plants. Primary productivity in kelp forests has been estimated at 350 to 2,800 grams of carbon per square meter.

Section 1: SYNOPSIS OF ECOLOGICAL LINKAGES REPORT



Kelp provides substrate for numerous benthic and epibenthic invertebrates, as well as food and shelter for many fishes, seabirds, and marine mammals. Colonies of bryozoans grow on kelp fronds. Several species of snails, including purple ring top snail and blue top snail, feed on kelp, while kelp crabs cling to the underside of kelp fronds. During periods of low productivity, sea urchins may emerge from protective crevices in rocky reefs to graze on kelp. At the surface, floating kelp masses are important habitats for juvenile fishes, particularly rockfishes and kelp surfperch. Schools of blue, black, and kelp rockfishes and bocaccio are generally recorded in the midwater kelp canopy. Gopher, copper, black, and yellow rockfishes, lingcod, cabezon, and greenlings tend to associate with the bottom of the kelp fronds. In addition, the sea otter has been described as a “keystone species” for its role in structuring kelp forest communities through predation of herbivores, particularly sea urchins, resulting in increased kelp growth.

Productivity from seaweeds can also have indirect effects on coastal food webs. Particulate and dissolved organic carbon that results from fragmentation and decomposition of kelps and other seaweeds can be consumed by suspension-feeding zooplankton or benthic invertebrates, providing a trophic link between kelps and higher-level pelagic consumers, such as fish. A small portion of the drift algae may be transported off the reef, where it can contribute to production in submarine canyons and the deep sea.

Productivity is reduced on rocky reefs below 30 m, where light levels are low and kelp is unable to flourish. However, the physical structure of rocky reefs does provide shelter for numerous benthic invertebrates and fishes. Shortbelly rockfish (*Sebastes jordani*), the most abundant rockfish species on the continental shelf and upper slope off California, are often associated with rocky reefs between 30-80 m depth. Various seabirds and marine mammals rely on shortbelly rockfish for food. Sculpin

(Cottidae) occur in shallow water and tidepools, as well as in deeper water around kelp forests, rocky reefs, and sand or mud bottoms on the continental shelf. Lingcod (Hexagrammidae), commonly associated with shallow rocky reefs, also occur in waters as deep as 300 m.

Soft bottom habitats on the continental shelf lack the physical structure and high biological production of kelp forests and rocky reefs. Species that live in soft sediments on the continental shelf are subjected to shifting sediments through wave action and near bottom currents. Some species that live in these habitats, such as crustaceans and mollusks, secure themselves in tubes and burrows. Other species, such as flatfishes, are camouflaged on sandy sediments of the seafloor by their color and shape.

Deep submarine canyons, such as Monterey, Ascension, Pioneer and Bodega, are remnants of riverbeds that deeply incised the continental shelf and slope during glacial periods. Because they cut into the continental shelf, submarine canyons support deep-sea communities relatively close to shore. Canyon walls are often steep and rocky, providing shelter for species, such as rockfishes and thornyheads, which are associated with complex physical structures. Canyon bottoms tend to slope gently and accumulate finer sediments, such as silt and mud, providing habitat for species such as flatfishes. In addition, the structure of submarine canyons affects the circulation of near-shore waters and the concentration of organisms in the water column.

Submarine canyons, submerged volcanoes, and other physical features under high pressure often concentrate gases and fluids beneath the sea floor. In some areas, where the sea floor is weak, these gases and fluids may be forced through the sediments, creating features known as cold seeps. Most cold seeps are found in the deep sea (600-3000 m) under conditions of low light, temperature, and oxygen, and high pressure. In spite of these difficult conditions, numerous organisms are adapted to life around cold seeps. Vesicomyid clams are the dominant species at cold seeps off central and northern California. These clams support chemoautotrophic bacteria in a symbiotic relationship. The bacteria use inorganic chemical compounds released by the cold seeps to produce organic compounds, which are used by their vesicomyid clam hosts.

Deep-sea communities depend on the distribution and quantity of primary production in surface waters, the rate of movement of organic material to the bottom, and the conditions of deposition and transformation of the organic matter in the sediment. A portion of dead organic matter produced in surface waters is transported to the sea floor either through passive sinking, or by active transport during vertical migration of plankton. In

the northeastern Pacific Ocean where production is particularly high, approximately 5-15% of the surface production eventually reaches the deep sea.

In a few places, extinct volcanoes or seamounts disrupt the monotony of the abyssal plain. Off central California, several seamounts (Gumdrop, Pioneer, Guide, and Davidson) are located near the bottom of the continental slope. Seamounts provide physical structures which support complex deep-sea communities of benthic invertebrates and some fishes.

Offshore Islands

The California coast is a tectonic subduction zone, inhibiting the formation of offshore islands. The few that do exist are extremely important sites for breeding by seabirds and pinnipeds. The largest offshore islands in the study region are the Farallon Islands, west of San Francisco. The Farallon Islands support some of the largest colonies of breeding seabirds south of Alaska. Numerous marine mammals, including northern elephant seals, Steller sea lions, harbor seals, and fur seals, haul out and breed on the Farallon Islands as well. Other important but much smaller breeding populations occur on rocks off Point Reyes, Año Nuevo Island, and on rocks off Big Sur. Subsurface features, e.g., the Farallon Ridge, Cordell Bank, and various seamounts, provide substrate and protection for diverse communities of benthic invertebrates and some fishes, as well.

BIOGEOGRAPHY

An understanding of biogeographic patterns and how they are influenced by ecological linkages enables management decisions to be placed in a spatial context relative to the distribution of marine resources. Distributions of marine species are determined by oceanographic phenomena, physical tolerances, and biological interactions. Each species responds to these factors in slightly different ways. Despite the physiological and ecological differences between species' response, there are many similarities in species' distributions, which can be used to define biogeographic regions. The transitions between biogeographic regions are more distinct outside the study area than within.

The geographic distributions of numerous marine organisms of the northeastern Pacific Ocean coincide with major oceanographic shifts. The biogeographic boundary at the Gulf of Alaska occurs at the transition between sea and land along the south coast of Alaska. The biogeographic transition at Vancouver Island corresponds to the eastern portion of the North Pacific Drift, which bifurcates in this region with part diverted north into the Gulf of Alaska and part diverted south along the western coast of North America as the California Current. The biogeographic transition at Point Conception corresponds to a shift in

Section 1: SYNOPSIS OF ECOLOGICAL LINKAGES REPORT

the oceanographic regime. At Point Conception, the California coastline turns abruptly east and the cool water moving south in the California Current is diverted offshore. The most significant biogeographic boundary in the study region occurs at Monterey Bay; however, other minor boundaries occur around points and bays along the coast.

In addition to the changes in latitudinal distributions, the diversity of species changes with depth. The changes in species composition and abundance are associated with physiological tolerances for temperature, exposure, light and nutrient input, as well as a wide range of biological interactions among species. At all latitudes, the average number of species of algae and marine gastropods increased with depth from high to low intertidal and subtidal zones. In addition, species that occur across several depth zones are likely to have broader latitudinal distributions than species that occupy a single depth zone. In contrast to the patterns observed for marine algae and gastropods, the average number of fish species declined with latitude and depth. The greatest numbers of fish species occurred south of 50°N latitude and shallower than 200 m.

For some species, the range of single individuals spans nearly the entire geographical distribution of the species. These species use local resources during long-distance migration, but no individual resource supports a resident population. Examples of these species include baleen whales that feed at highly productive sites along their migration route, and seabirds that use estuaries along the coast as resting and feeding sites during their annual migrations. For other species, the entire geographical range far exceeds the range of an individual. Many intertidal invertebrates and fishes have dispersal and sedentary phases during their life cycles. Examples of these species include barnacles, mussels, and clams that settle into intertidal habitats, and rockfish that settle into kelp forests or rocky reefs after a pelagic larval stage.

CONCLUSIONS

Within the study region there are many distinct ecosystems each hosting a unique assemblage of organisms. In addition to describing these key ecosystems and species in the region, the Ecological Linkages Report provides information on linkages within and between these systems. By understanding the climatic, oceanographic, physical and biological influences operating together to shape the regional biogeography, the background exists for the biogeographic analyses to be interpreted. The "Biogeographic Analyses" section complements the synthesis of literature in the Ecological Linkages Report with a data driven look into the biogeographic patterns evident around the sanctuaries. The analyses provide a spatially explicit view of marine resources within the study area from which management decisions can be better enacted. It is important that the

results from the biogeographic analyses are interpreted within the context of the Ecological Linkages Report as it demonstrates the understanding that the patterns presented in the Geographical Information System are dynamic in nature due to the multitude of factors operating to shape them. Changes in any of these factors can result in changes to the biogeography of the region.

REFERENCE

Airamé, S., S. Gaines, and C. Caldow. 2003. Ecological Linkages: Marine and estuarine ecosystems of central and northern California. NOAA, National Ocean Service. Silver Spring, MD. 163 p.



Joe Heath

Section 2: BIOGEOGRAPHIC ANALYSES

INTRODUCTION

The biogeographic analyses component is the cornerstone of the overall assessment to support the joint management plan revision process. The data, analyses, and supporting information are linked using statistical and GIS tools to visualize the location of significant biological areas or “hot spots.” There were many different ways to analyze and organize the biological data compiled for this assessment. To efficiently support the management plan revision process, only a limited number of analytical options were selected based on reviewer’s comments on the Interim Product, mission of the NMSP, technical review meetings, and peer review workshops. These key analyses are presented in this document and on the CD-ROM. In addition to these results, spatial data and information on the companion CD-ROM enable NMSP staff, advisory councils, and research partners to conduct additional analyses not specifically addressed in this product.

A critical step in the biogeographic analyses component was the extensive effort to have data, analytical approaches, and results peer reviewed. Initial results from the suite of analyses were presented to experts on marine ecosystems of north/central California, as well as to the originators of the data sources in an attempt to improve the analyses. The role of expert review and input has been considerable, and the contributions made by experts have significantly enhanced the analyses.

ASSESSMENT PROCESS

To aid in focusing on the most important analyses, the biogeographic assessment process displayed in Figure 6 was utilized. This process is currently being implemented through a joint NMSP and NCCOS Biogeography Team effort to initiate biogeographic assessments across all sanctuaries within the next five years. The process is organized around development of biogeographical data layers, integrated analyses, and specific products to aid in sanctuary management plans (Kendall and Monaco 2003). Thus, the integration of partner’s comments and use of the biogeographic assessment process resulted in the analyses and results presented in this document.

Biogeographic data assembled for this project were derived from many sources (see section 4), including NOAA Fisheries, academia, state government, and data housed within the NMS and Biogeography Programs. The biogeographic data cut across various themes, such as species distributions and habitats, and are integrated using a common spatial framework in a GIS. The GIS enables a user to select particular data layers to be displayed, combined, and manipulated in a wide variety of ways to achieve specific analytical objectives (Figure 6).

The use of the GIS enabled species-specific data, such as distribution and abundance data or community metrics (e.g.,

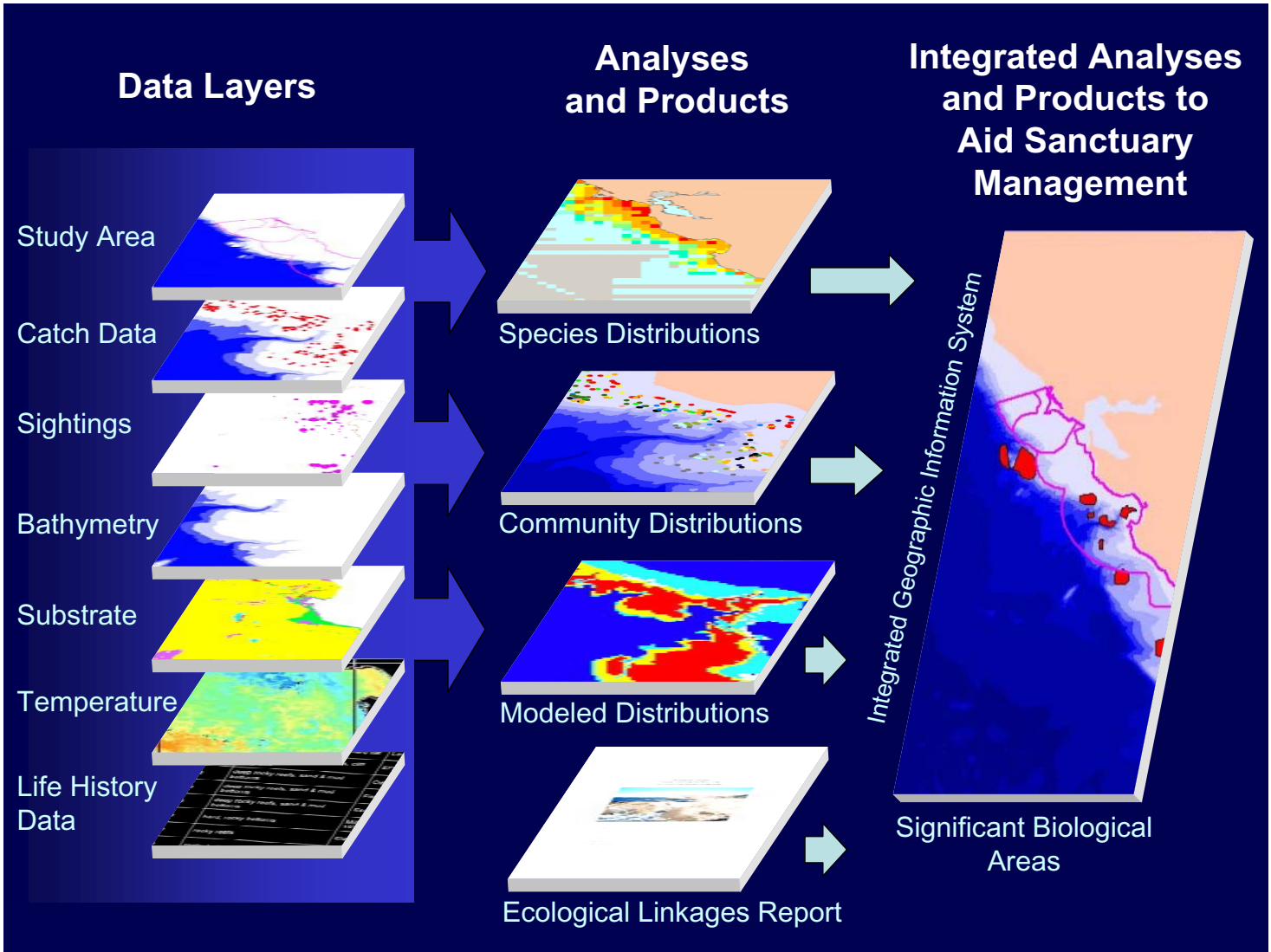


Figure 6. Biogeographic assessment process.

species richness statistics), to be directly linked to specific areas or habitats they correspond to across the study area. The GIS also facilitated integration of multiple data types and sources into a common spatial and temporal framework (Gill et al., 2001). The following suite of map products quantitatively defined significant biological areas that are within or adjacent to existing boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay National Marine Sanctuaries. The GIS-based products are intended to aid in evaluating current sanctuary boundaries relative to biological resources and habitats (Figure 7), explore options for environmental protection of existing NMS areas, identify additional biologically important areas, and evaluate alternative management strategies.

To develop this capability, a suite of analyses were conducted that were most appropriate in addressing NMSP natural resource management issues. The biogeographic assessment framework (Figure 6) aided in targeting the suite of analytical approaches to define biologically significant areas in support of the sanctuary management plan reviews. Categories of analysis include: temporal and spatial analysis of individual species’ distributions, species assemblage analyses, habitat suitability modeling, and community metrics within and across species groups. Important individual species maps were developed from a number of data sets to visualize species presence and/or abundance data within the study area by season. Where possible, well-established breeding colonies, rookeries, and high concentrations of species are displayed on the digital maps. The single species maps enabled various groupings of

species within a group, such as by family (e.g. rockfish), and comparison of spatial patterns between groups. Analysis of spatial patterns resulted in information on the relationships between individual species, between assemblages of species, and of the relationship of species to specific environmental and habitat parameters. Furthermore, the compilation and integration of individual species maps were used to calculate community metrics, such as total richness or diversity of fish and marine bird species, at a specific location.

To define species assemblages, multivariate techniques were applied to various data sets to group organisms found at specific sampling sites. The assemblage analyses defined species groups across the study area. By visualizing the assemblages geographically, areas of overlap became apparent and group habitat affinities, such as depth range, were delineated.

Species habitat suitability index modeling (HSI) studies were undertaken for 20 fish and invertebrate species in an attempt to characterize areas within the study region that suffered a lack of sampling data, particularly in near-shore habitats. The integration of HSI models into a GIS provides a spatial depiction of species habitat suitability models for individual species by integrating information on species habitat affinities and the distribution of those habitats in space and time (Brown et al., 2002; Monaco and Christensen 1997). The modeling component of the biogeographic analyses is a necessary step due to the incomplete distribution of sampling data across the entire study area. Thus, species that were representative of the assemblages described above and/or other key species were selected for modeling their potential distribution. The composite set of species habitat suitability models contributed to defining significant biological areas within the region.

Measures of community structure for fishes and marine birds were calculated independently by species group, compared, and, where applicable, integrated. Convergence of overlapping spatial patterns defined significant biological areas based on a number of criteria (e.g., high species abundance, high species diversity).

Thus, the biogeographic analyses component was a result of interpreting or visualizing the analytical results from statistical analyses, ecological modeling, and integration of results across biota and habitats. The cumulative results aided in assessing the biogeographic patterns in the study with regard to the distribution of individual species, species assemblages, and species habitat utilization patterns.

REFERENCES

Brown, S.K., K.R. Buja, S.H. Jury, M.E. Monaco, and A. Banner. 2000. Habitat suitability index models for eight fish and inver-

Section 2: BIOGEOGRAPHIC ANALYSES

tebrate species in Casco and Sheepscot Bays, Maine. North American Journal of Fisheries Management 20:408-435.

Gill, T.A., M.E. Monaco, S.K. Brown, and S.P. Orlando. 2001. Three GIS tools for assessing or predicting distributions of species, habitats, and impacts: CORA, HSM, and CA&DS. In: Proceedings of the first international symposium on geographic information systems (GIS) in fishery science. Nishida, T., Kailola, P. and Hollingworth, C.E. (Eds.). pp 404-415.

Kendall, M.S. and M.E. Monaco. 2003. Biogeography of the National Marine Sanctuaries: A partnership between the NOS Biogeography Program and the National Marine Sanctuary Program. January 2003. 8pp.

Monaco, M.E. and J.D. Christensen. 1997. Biogeography Program: Coupling species distributions and habitat. Pages 133-139 in G.W. Boehlert and J.D. Schumacher, editors. Changing oceans and changing fisheries: Environmental data for fisheries research and management. National Marine Fisheries Service Technical Memorandum NOAA-TM-NMFS-SWRSC-239, Pacific Grove, California.

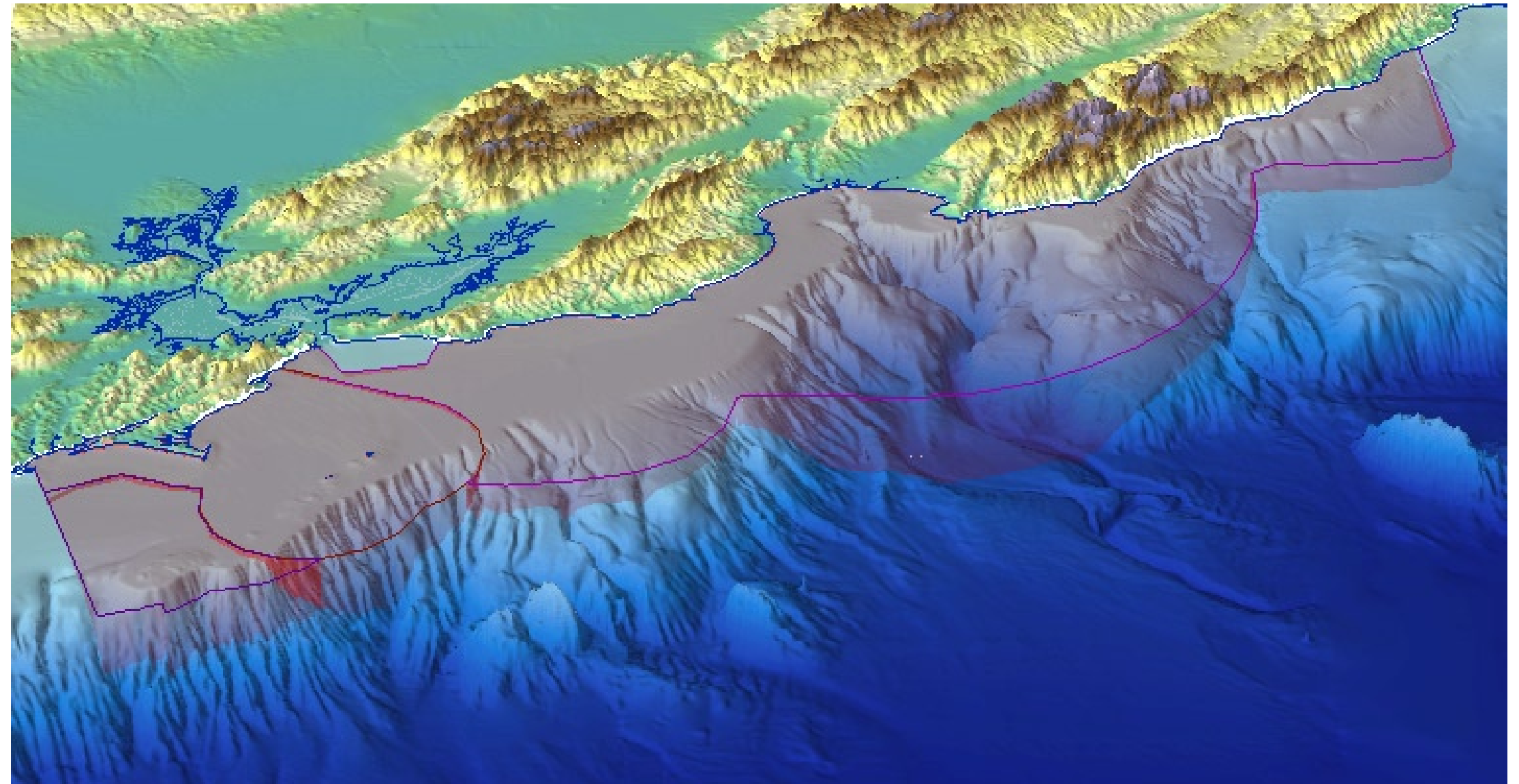


Figure 7. 3-D image of bathymetric relief within and adjacent to the sanctuaries.

Section 2.1: BIOGEOGRAPHY OF FISHES

INTRODUCTION

The biogeography of fishes section is a robust statistical analysis of fish and a few economically important macro-invertebrates. A two-pronged approach was conducted to examine both fisheries-dependent and independent catch data and model the potential distribution and relative abundance of selected species (Figure 8). Analysis of fisheries data can be a slow process which often requires extensive exploratory statistical techniques to increase our understanding of the data before presenting reliable and salient results. Many data sets were evaluated, however, only four data sets that were spatially comprehensive within the study area were analyzed: 1) the California Department of Fish and Game fishery dependent recreational fishing trips targeting rockfish (CDF&G recreational); 2) the National Marine Fisheries Service fishery independent benthic trawls on the continental shelf (NMFS shelf trawls); 3) NMFS fishery independent benthic trawls on the slope (NMFS slope trawls); and 4) the NMFS fishery independent trawls in midwater (NMFS midwater trawls). Detailed information on these trawls is given in each respective section. The NMFS trawls on the continental shelf and slope provide information on the diverse demersal fish assemblages found on trawlable habitats between 50 and 1280 meters depth throughout the study area. Pelagic fish encountered either as the trawl descended or ascended are also included with these analyses. The CDF&G recreational hook and line data complements the NMFS data sets by providing information on midwater as well as demersal species. The recreational data was collected over soft bottom and hard bottom habitats between 5 and 200 meters depth. The NMFS midwater trawl data targets juvenile rockfish and provides information on fish and invertebrates found in the neritic environment during the upwelling season.

Even though the spatial extent of this data set does not cover the entire study area, it provides a source of information on the neritic environment, which is important as juvenile habitat, and as the base of the food web for marine birds, fish, and marine mammals.

Due to time constraints, analysis of all species individually was not feasible. Instead, all four data sets were analyzed using multivariate statistics to identify species assemblages, site groups, and the location of the species assemblages in space using a Geographic Information System (GIS). For the multivariate statistics, species were included in an analysis if they were captured in at least 5% of the collections. Through

all four data sets, 119 species were analyzed. A complete list of species included in the assemblage analyses can be found on the CD-ROM. In addition, community metrics, including species richness, species diversity, and rockfish richness were calculated for the NMFS shelf and slope trawls and the results presented spatially using GIS. However, due to spatial and temporal limitations of available data, (i.e. NMFS demersal trawls have no information on rocky or shallow areas (<50 meter) and contain trawls only for the months of June through November) areas such as Cordell Bank and the Farallon Islands are not adequately sampled. Therefore, habitat suitability modeling (HSM) was conducted to supplement the analysis of catch data, and to model the potential distribution

of fish and invertebrate species across the study area (Brown et al., 2000). Thirty two species of fish and invertebrates were initially investigated through literature searches to determine if sufficient information was available to model potential distributions. The process of determining which species to include in the modeling procedure included consultation by the sanctuary staff, and integration of information on the economic and ecological importance of the species as well as initial results on species assemblages. Of the 32 species initially investigated, there was sufficient information available to conduct HSM on the adult and subadult stages of 14 fish species, and adult stage of 4 fish and 2 invertebrate species. Habitat suitability models were either derived from an analysis of a portion of the NMFS

trawls on the continental shelf and slope or derived from species habitat affinities described in the literature. Model results were validated with NMFS trawls on the shelf and slope (a different subset than that used to create the affinities) or CDF&G recreational catch data. Model results for 3 species are included in the main body of this document, with the models for the rest of the species included in the CD-ROM.

The integration of the fish and invertebrate analyses is shown in Section 3. For example, a comparison of important areas derived from the diversity of NMFS trawls and those derived from overlays of the HSM's was conducted to define significant biological areas. In addition, aspects of the *Ecological Linkages Report* were qualitatively incorporated into the assemblage and HSM discussions to aid in interpretation of these analyses.

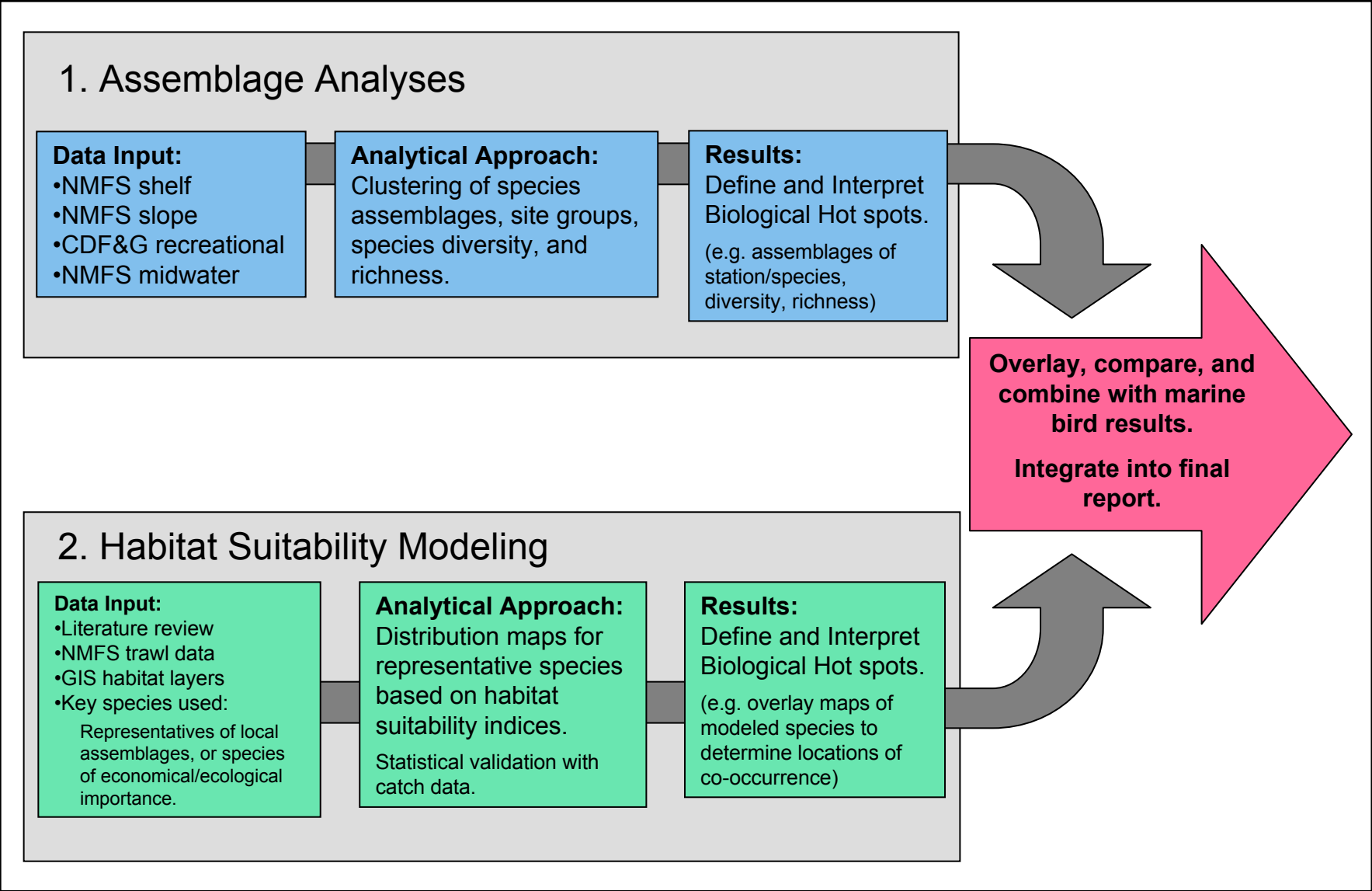


Figure 8. Biogeographic approach to fish analysis.

Subsection 2.1.1: ASSEMBLAGE ANALYSES

INTRODUCTION

No species exists in isolation from other species or their environment. Monitoring species individually may cause managers to miss important interactions (Chavez et al., 2003; Worm and Myers, 2003; Baraff and Loughlin, 2000; Estes et al., 1998). In addition, individual species' abundance may be considered sustainable in the context of a fishery, but still be low enough to influence ecosystem dynamics and health (NMFS 2001). There has been a growing recognition that effort needs to be extended toward understanding the entire ecosystem. The National Marine Sanctuary Program is tasked with ensuring the continued health of the ecosystems contained in the sanctuaries. However, important species-species interactions and species-habitat interactions are still not well understood. Abiotic (e.g., habitat preferences toward depth or sediment) and biotic (e.g., presence or absence of prey, predators) factors can impact the importance of an area to fish. Elucidating habitat characteristics that are most important to animals, and understanding the co-occurrence of species, is a first step in determining areas that should be managed as "essential" habitats. This study aids in clarifying the interactions among species and between broad scale habitat characteristics and species on the scale of the commercial and recreational fisheries. Even though these data sets were originally deployed to collect information necessary for setting fishing limits, these data sets can provide preliminary information on multi-species interactions. Recreational hook and line drifts covering approximately one kilometer, demersal trawls on the continental shelf and slope covering one kilometer, and fifteen minute trawls in midwater, were analyzed to determine species assemblages, site groupings, and the interaction between species and locations. In addition, analyses were completed to determine larger scale environmental variables that were significantly different among identified groups. Due to limitations of the data sets (section 4), and the lack of results on individual species' distributions, habitat suitability models (section 2.1.2) for selected species were completed to complement this analysis.

The primary objective of the assemblage analysis is to define spatial biogeographic patterns of fishes and macro-invertebrates within the study area from Point Arena to Point Sal in California. The study is based on a synthesis of four primary databases of fish and invertebrates that were spatially comprehensive throughout the study area including: 1) the California Department of Fish and Game fishery dependent recreational fishing trips targeting rockfish (CDF&G recreational); 2) the National Marine Fisheries Service fishery independent benthic trawls on the continental shelf (NMFS shelf trawls); 3) NMFS fishery independent benthic trawls on the slope (NMFS slope trawls); and 4) the NMFS fishery independent trawls in midwater (NMFS midwater trawls). Detailed information on these surveys is given in each respective section. Databases that were limited

in content and spatial coverage were not utilized in this analysis, but were used to help interpret the results.

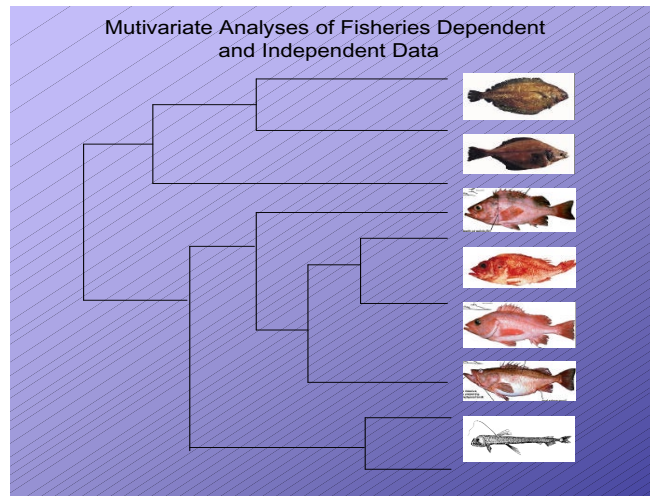
Five specific objectives of the assemblage analysis (all of which aim to increase our understanding of the biogeography of fishes and macro-invertebrates in relationship to their environment, as well as identify important areas or habitats within the study area), were as follows:

1. Identifying spatial patterns and hot spots in community metrics (diversity and richness);
2. Determining which species tended to be caught together (species assemblages);
3. Analyzing fishing locations to determine which locations contained similar catches (site groups);
4. Resolving where the species assemblages were being caught by combining results from objectives 2 and 3 and then utilizing GIS to map the results; and
5. Identifying significant relationships between site groups identified in objective 3 and broad scale habitat characteristics (bathymetry, bathymetric complexity, and large-scale habitat classification).

Community metrics can be used to determine which areas are important to multiple species. Experts in California have acknowledged a management need to increase our understanding of fish species interactions (objective 2) (Starr, 1998) and the interactions between fish assemblages and habitat (objective 5) (Starr, 1998; Yoklavich et al., 2000, 2002). Studies exist that identify either species assemblages or site groups (see below), but so far none have integrated multiple data sets, provided the interaction between species assemblages and site groups, nor presented spatially explicit results. The results of these analyses aid in defining the region's biogeography based on the spatial pattern of fishes and macroinvertebrates.

REVIEW OF RELEVANT LITERATURE

Due to the economic importance of recreational and commercial fisheries in California, several studies have been completed that look at species co-occurrences or species interactions with their environment. NMFS publishes yearly reports on the status of demersal fish species by analyzing results from their shelf and slope trawls (Turk et al., 2001; Weinberg et al., 2002; Lauth, 2001; Shaw et al, 2000). Zimmerman et al. (2001) looked at the biomass of demersal species to determine NMFS shelf trawls that did not fish the bottom as intended. He then looked



at the effect these trawls had on the estimates of biomass of selected species through time. Based on Zimmerman's results, we excluded these abnormal "water hauls" from our analyses. Williams and Ralston (2002) analyzed data from NMFS shelf trawls to determine rockfish species assemblages. The same data were used in this analysis; however, the multivariate statistical method utilized, the spatial coverage employed, and the species examined were different. The overall conclusion from Williams and Ralston was that rockfish richness

was highest at a depth of 200-250 meters, where the shelf and slope meet, and that depth and latitude were the main determinants of rockfish assemblages. Jay (1996) analyzed the 1977-1992 NMFS shelf trawls to determine site groups that contained similar catches. Using 33 species of fish, he identified 23 site groups, many of which contained the same species, but with different relative abundance. Even though depth and latitude showed some influence on site groups, overall he found little association between the site groups and a suite of environmental parameters.

Gabriel and Tyler (1980) used data from the Oregon Department of Fish and Wildlife Trawl Survey and the West Coast Joint Agency Rockfish Survey to look for site groups from California to Alaska. They differentiated three large site groups: "intermediate" at less than 145 meters, "deep" between 145 and 200 meters, and "slope" greater than 200 meters deep. They found that site groups were "strongly associated with depth contours". Matthews and Richards (1991) compared gill net catches from trawlable and untrawlable areas to determine if untrawlable areas could be considered de-facto fish reserves. Even though some species overlapped, they concluded that the species assemblages were significantly different; suggesting that species assemblages determined from trawls cannot be extrapolated to non-trawlable habitats.

Only a few studies have analyzed recreational hook and line data. For a general analysis of a species' specific decline in recreational catch see Love et al. (1998), Mason (1998), or Wilson-Vandenberg et al. (1996). Mason (1995) analyzed various CDF&G recreational fishing surveys and documented trends in effort, fishing location, and species catch. She documented two principal rockfish assemblages and distinguished them by depth (less than 70 meters and greater than 70 meters). Sullivan (1995) used the CDF&G recreational fishing data (1987-1992) to determine site groups. His overall conclusion

was that the rockfish management groups could be defined, and that both depth and latitude were important.

Even though the neritic zone is ecologically important, little research has addressed the midwater environment. Cailliet et al. (1979) described fish and invertebrate species co-occurrences in anchovy purse seines, and midwater trawls. An extremely thorough report by Larson et al. (1994) looked at the NMFS midwater trawl results in conjunction with local environmental conditions to determine juvenile rockfish assemblages. Their results emphasize the ephemeral nature of the pelagic environment, but they were able to document two consistent spatial trends: 1) the rockfish are larger inshore than offshore, and 2) there was a north/south gradient in species composition and abundance. Moser et al (2000) described changes in rockfish larvae abundance in CalCOFI plankton tows from 1951 to 1998 in response to adult biomass and environmental conditions. He concluded that over-fishing as well as decadal shifts in environmental conditions were affecting the stocks.

Underwater submersibles have been used to describe fish assemblages and their interaction with habitat at spatial scales relevant to the fish themselves. Yoklavich et al. (2000 and 2002) surveyed Soquel Canyon and Big Creek Ecological Reserve on the Big Sur coast, Field et al. (2002) looked at Big Creek Ecological Reserve, while Hixon et al. (1991) and Hixon and Tissot (1992) researched Haceta, Coquille, Daisy, and Stonewall Banks off the Pacific northwest. These results are very important to managers because they show fish and habitat interactions on very small scales. However, many of the results from these studies are not comparable with the current studies due to large differences in scale. Hixon et al. (1991) documented that the species composition observed from the submersibles was different than that seen in trawls. The results from these studies reveal the importance of habitat, especially rugosity, to fish species composition.

Substantial declines in the standing stock biomass of economically important rockfish species (Ralston, 1998) prompted NMFS to organize a symposium to discuss the implications of no-take areas for rockfish in September of 1997. Eleven plenary papers and six case studies are available online, and cover a range of topics. Starr (1998) provided a thorough evaluation of the potential of rockfish no-take reserves. He expressed a management need for the identification of species assemblages. Once assemblages are identified, management can address actions for adequate protection of each species assemblage. Starr also suggested protecting rectangular areas that cover 20-50 km of the coast and extend west to the edge of the continental shelf.

Subsection 2.1.1: ASSEMBLAGE ANALYSES

INTRODUCTION TO CLUSTERING

The use of multivariate analyses is gaining popularity in ecology and fisheries management (McGarigal et al., 2000; Paukert and Wittig, 2002), but can be confusing due to the availability of many statistical techniques. Therefore, this section provides a basic introduction to the principles of clustering, one form of multivariate analysis. Interested readers should reference Boesch (1977), Gauch (1982), or McGarigal et al., (2000) for more detailed information on clustering than will be provided in this brief introduction. Clustering is “a technique for optimal grouping of entities according to the resemblance of their attributes as expressed by given criteria” (Boesch, 1977) or, in short, a method that places things (sites, species, etc.) into groups. Clustering uses statistics to determine these groups, but the method also possesses aspects that are subjective and require an understanding of the ecosystem being analyzed. There are five steps to clustering, which all have some aspect of subjectivity (adapted from Sullivan, 1995): 1) the choice of data, including what data to include or remove, and how to transform and standardize that data; 2) the choice of a resemblance metric (can be based on similarity or dissimilarity); 3) the choice of clustering model; 4) the choice of number of groups (or level of similarity) and; 5) the choice of whether or not to reassign objects to more appropriate groups. The following is a more detailed description of each of these five steps.

The choice of data to include in the analyses can influence results in many ways. Rare species are usually removed from analyses because they can have a disproportionate influence on the resulting clusters. What is considered “rare” can vary for analyses, but typically species found in less than 5% of the trawls/catches are removed (Gauch, 1982). Additionally, the transformation and standardization of the data may affect the influence of rare and abundant species. Binary data (presence/absence) weights all species the same, and reduces the influence of abundant species while increasing the influence of rare species (Boesch, 1977). Transformations are needed because most ecological data do not conform to the assumptions of a normal distribution and homogeneity of variances required for parametric analyses (Boesch, 1977). Transformations decrease the variation between abundant and rare species, thereby reducing the influence of abundant species.

The clustering method dictates the way that groups are formed. The two classes of clustering are: 1) hierarchical, which show the relationship between groups in dendrograms, and 2) non-hierarchical, which do not. Hierarchical clustering may be biased because the researcher can choose the results that best match expectations (Williams and Ralston, 2002); however, it is advantageous because it clearly shows the relationship between the resulting groups.

Within hierarchical clustering, the choice of resemblance metric (a formula that determines how similar two things are) and clustering model (a method that groups things based on their resemblance metrics) can also have an influence by adjusting the importance of abundant and rare species and changing the importance of zero values (Gauch, 1982; Boesch, 1977; McGarigal et al., 2000). Common resemblance metrics used in ecology are the Bray-Curtis, Euclidean distance, Jaccard, and Pearson correlation coefficients. Common clustering models include Ward’s minimum variance, average linkage, centroid linkage, and single linkage. Because of chaining, not all outputs from cluster analyses can be utilized. When chaining occurs, entities fuse to a few nuclear groups one at a time rather than forming new groups, and make it impossible to divide the data into meaningful smaller groups (Boesch, 1977).

Hierarchical clustering results in a tree diagram, called a dendrogram, which shows the linkages between all of the entities and groups at different levels of similarity. Various objective methods, such as scree plots, are used to determine what level of similarity is important or how many groups are created. A scree plot shows the dissimilarity values plotted against the number of clusters such that breaks in the level of dissimilarity are revealed through the shape of the curve (McGarigal et al., 2000). Experts recommend combining this objectivity with ecological knowledge to determine clustering results that are ecologically meaningful (Boesch, 1977). The final decision when clustering is whether to reclassify entities into more appropriate groups based on some identified criterion. This step has created controversy because of the subjectivity introduced.

For comparison, a brief introduction to another widely used form multivariate analysis, the Principal Component Analysis (PCA), is provided. PCA reduces the dimensionality of data (Gauch, 1982, McGarigal et al., 2000). One difference between the results from PCA and hierarchical clustering is that in clustering each species is ultimately assigned to one and only one group. In PCA, only species with a certain loading (i.e. level of influence) are included in a group. This means that in PCA some species are never assigned to a component, and others are assigned to more than one. This can be a drawback because often very important species that are found everywhere are never attributed to any group. In clustering methods, since every fish must be placed into a group, species which are found everywhere can be grouped together. At the same time, species which are only marginally associated with a group can be added to a group.

For this study, an extensive exploration was conducted on the data using multiple data transformation, similarity metrics, and clustering models. Ultimately, one method was chosen, and

the reasons behind those decisions are provided within the following detailed methodology section.

DETAILED METHODOLOGY

To reduce the amount of material that is repeated with each section, a detailed methodology for all four data sets is presented here, with only a brief overview provided in each section. Figure 9 is an example of the clustering methods using hypothetical data. The first objective of this study was to look for patterns in community metrics. For these analyses, all unknown species, and those without an abundance estimate, were eliminated. The Shannon index (H') was calculated for each NMFS shelf and slope trawl based on the following equation:

$$H' = - \sum_{i=1}^S \left[\left(\frac{n_i}{n} \right) \ln \left(\frac{n_i}{n} \right) \right]$$

Where S is the number of species, n_i is the number of individuals found of species i, and n is the total number of individuals (Shannon and Weaver, 1949). Richness (total number of fish species caught) was also enumerated for each NMFS shelf and slope trawl. In addition, the rockfish richness was calculated by counting the number of *Sebastes* and *Sebastolobus* species caught in each trawl.

Due to the overlap in trawls between years (boats often returned to approximately the same area each year), it was sometimes difficult to determine spatial trends in diversity. Therefore, mean diversity and mean richness were calculated for 5' grid cells (approximately 5 km by 9 km cells, although actual dimensions vary with latitude) throughout the study area. The 5' grid cell size was utilized because it was employed in other analyses (bird, mammal, and environmental maps) and facilitates the comparison of results among these analyses.

Both clustering analyses (objectives 2 and 3) began with either a site by species or species by site matrix of presence/absence or log adjusted abundance. All species that were present in at least 5% of the trawls were included in this analysis. This number was chosen because it is a commonly used method in fisheries management (Gauch, 1982), and because it reduced the number of zero values in the data set while keeping an adequate number of species for analysis. Since the raw abundance data did not conform to assumptions of a normal distribution and homogeneity of variances, either log transformations (if effort was available) or presence/absence (if no effort was provided) were used. No standardization was completed because correlation coefficients were used. Exploratory analyses were run to investigate multiple resemblance metrics (including Euclidean Distance, Jaccard, and Pearson correlation matrices) and multiple clustering models (including Ward’s minimum variance, average linkage, centroid linkage, and single linkage).

Only the Ward’s minimum variance (it calculates an internal dissimilarity matrix) and the 1-Pearson correlation with average linkage consistently produced results without chaining, and were therefore interpretable. The Pearson method was chosen over Ward’s primarily because the results were very similar to the results from principal component analysis (both methods are based on a correlation matrix), but also because the results showed spatial patterns when mapped.

To determine which fish species tended to be caught together (species assemblages; objective 2), an index of dissimilarity between species was calculated as 1-Pearson correlation coefficient, with the resulting matrix of species dissimilarities clustered by using average means as discussed above. Changes in fishing depth or the abundance of target species through time could influence the results. Therefore, a second analysis was run using only current data (1993+ for recreational, 1989+ for shelf trawls), so that a comparison of species associations from all the data and current data could be completed. The determination of what should be considered “current” was based on the expert opinion of the scientists who collected the data (pers. comm. Deb Wilson-Vandenberg and Mark Wilkins) according to known shifts in effort or species abundance. Differences in assemblage groups between the entire data set and current data are noted.

To determine which locations contained similar fish catches (site groups), the 1-Pearson correlation clustering method, as explained above, was used again, but this time to cluster sites with similar catches. No secondary analyses with a random subset or current data were run because the influence of such parameters could be inferred by looking at the date of each trawl in each group.

In order to decide how many groups to keep, statistical methods (scree plots) were employed to determine where breaks in the similarity level occurred, then group composition was analyzed to determine the best ecological groupings (i.e. if smaller or larger groups would provide a better ecological explanation). Expert opinion on ecologically relevant groups was solicited at review meetings held in Seattle, San Francisco, and Monterey in October, 2001. No reclassifications were completed in this study. Instead, a modified bootstrapping procedure was implemented. Fifty random samples of one-half or three-quarters of the data were extracted and run through the clustering process. The amount of data included in the random analyses depended on the size of the original data set; if the data set was too small, samples consisting of half of the data often had zero catch for some species, creating error messages when running the analysis. The results from the random samples were used to determine the stability of the species assemblages in the given data set.

Subsection 2.1.1: ASSEMBLAGE ANALYSES

In order to combine these two analyses and resolve where the fish assemblages were being caught (objective 4), the average frequency of occurrence for species assemblages was calculated for each site group to determine the overlap between the site and species groups. By looking at the frequency of occurrence of species assemblages in each site group, it was possible to determine which species groups were influential in forming the site groups. Species groups were considered influential if, on average, species were present in 25% of the trawls. Since rare species had low frequency of occurrence for all site groups, 25% is a reasonable number when rare and abundant species are averaged. Spatial distribution of the site groups was determined by mapping the site groups in GIS.

For management purposes, it is important to understand which environmental characteristics influence species distributions. Analyses of variance (ANOVA) were conducted to determine if there were significant differences in bathymetry, bathymetric complexity, and gross sediment type between the site groups at the scale of this analysis. Bottom depth was measured in the field for each of the four data sets. Using ArcView, individual trawl locations were overlaid on the sediment (pp. 38) and bathymetric complexity (pp. 16) maps and the underlying parameters extracted. For the midwater trawl, other environmental conditions measured in the field, such as water temperature, salinity, and density, were also tested.

Bathymetry appeared to be the overriding influence in determining fish assemblages. Attempts were made to statistically remove the influence of bathymetry from the data and then re-analyze the data for assemblage patterns caused by secondary influences. However, two general problems were encountered. First, the standard statistical procedure to remove the influence of bathymetry required a linear relationship between species abundance and bathymetry. Unfortunately, the relationship between species abundance and bathymetry was non-linear even after various transformations were tried. Experiments with spline-fitting were also unsuccessful. A major problem was the presence of zero species abundance values for those depths the species assemblages were not present. Secondly, the species abundance data were collected over narrow ranges of other influences, such as bathymetric complexity and substrate/sediment size. Again, the problems of non-linearity and zero species abundance prevented further conventional statistical analyses.

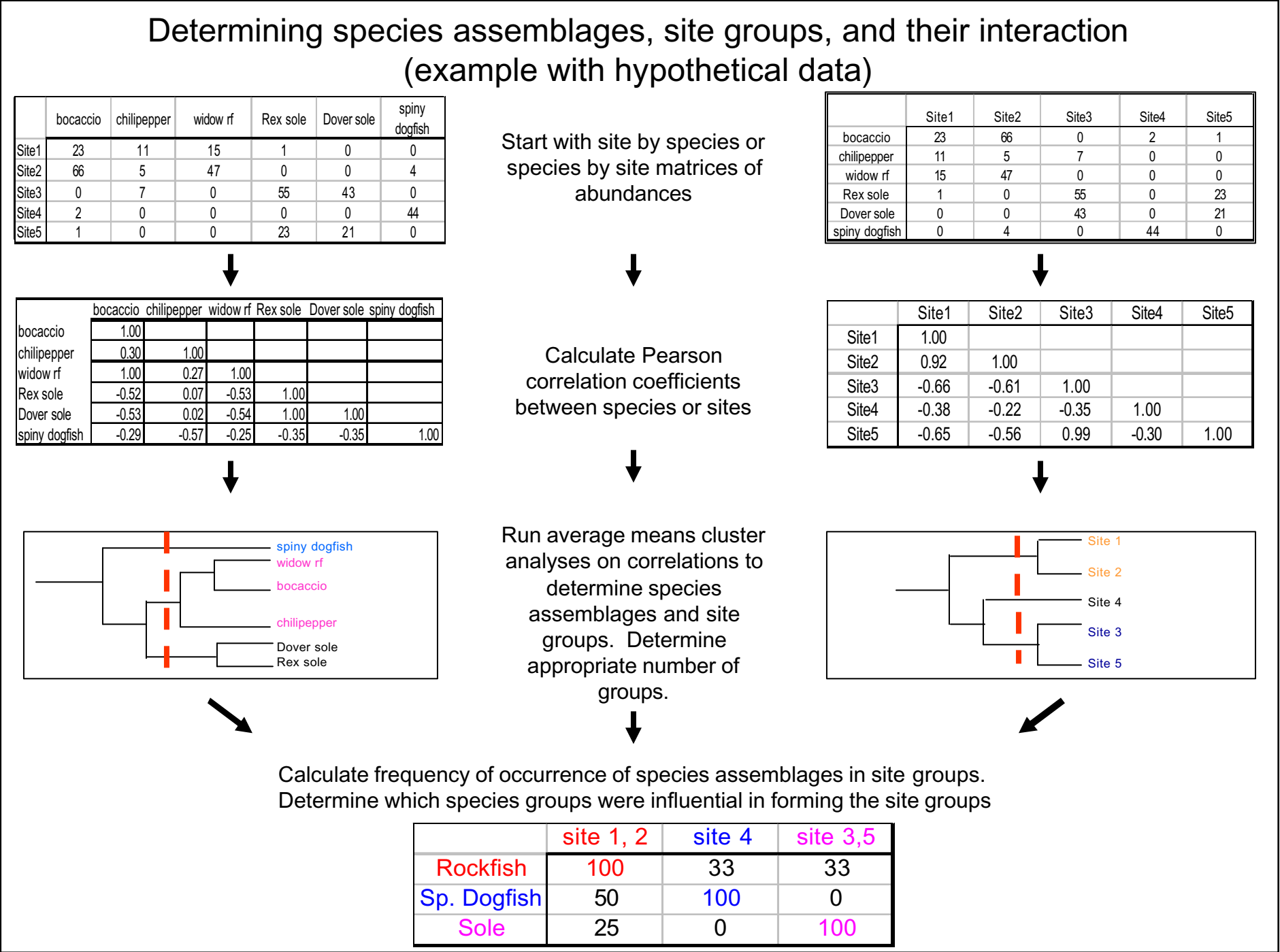


Figure 9. Hypothetical example of the methods used to determine species assemblages, site groups, and the interaction between species assemblages and site groups.

Subsection 2.1.1: ASSEMBLAGE ANALYSES

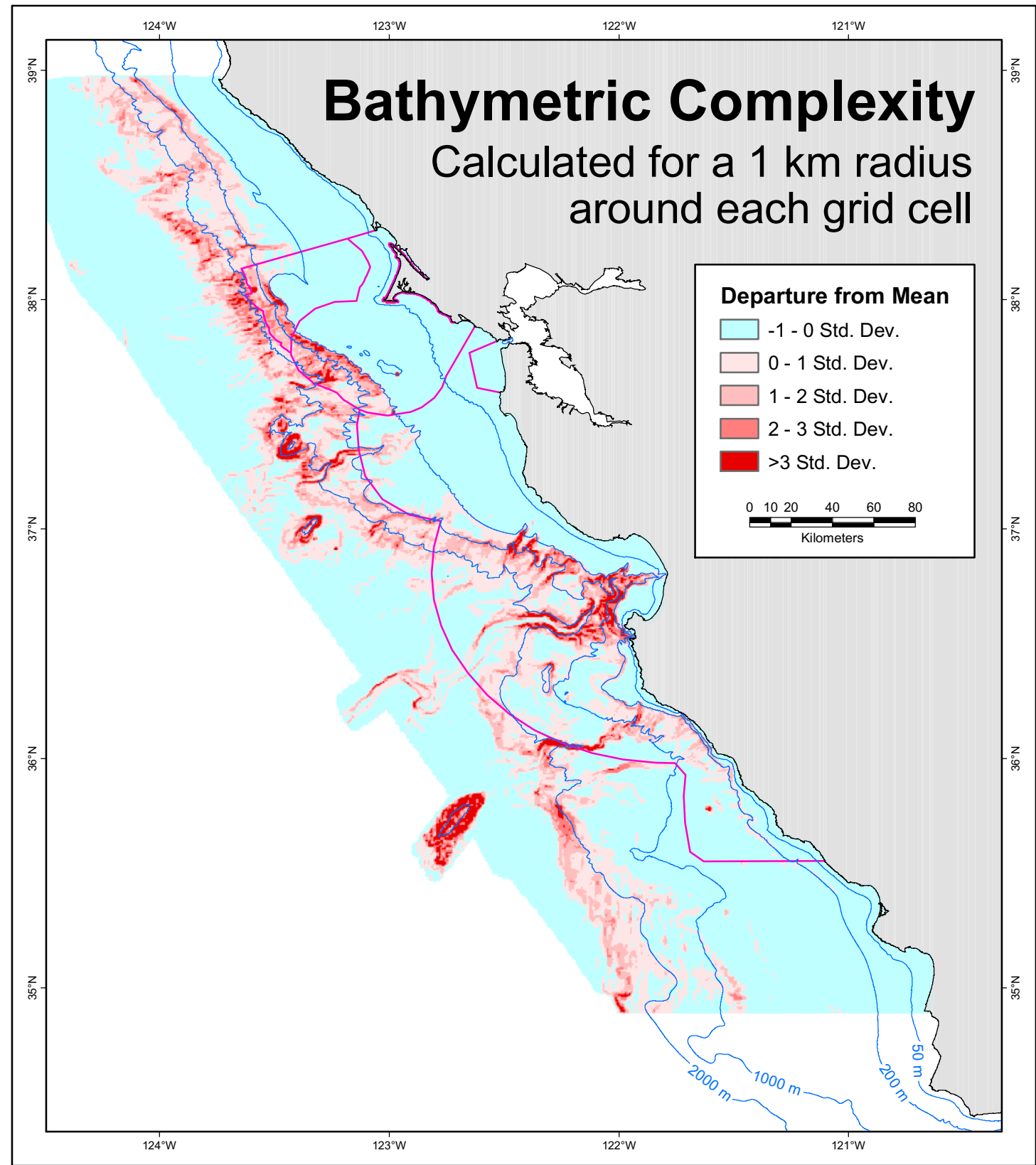


Figure 10. Standard deviation of bathymetry calculated for a 1 km radius around each cell. Results are presented in standard deviations above or below the mean.

ABOUT THIS MAP

Figure 10 displays bathymetric complexity derived from high resolution bathymetry. Bathymetric complexity is calculated for each cell as the standard deviation of depth for all grid cells within a 1 kilometer radius. The range of resulting bathymetric complexity is large, and the majority of cells show a low variance. Therefore, in order to visualize differences, results have to be displayed as standard deviations above and below the mean. The areas in blue are relatively flat with little slope, and the darker red shows the highest variance. Results highlight the edge between the shelf and slope areas, and create a dramatic visual for the canyons and seamounts.

DATA SOURCES

Results were calculated from 3 arc second (nominally 70 x 70 meters) bathymetry derived from NGDC and MBARI data sources. All available multibeam points were used in the area. Hydrographic survey data (echo sounder data) was eliminated from the interpolation if it overlapped with multibeam data. Vertical and horizontal correction was performed on all data prior to incorporating it into the data set. All data were triangulated and gridded using "The Vertical Mapper" extension with MapInfo 6.5. Cell size varies depending on the available data for each area, with a minimum cell size of 70 x 70 meters.

METHODS

Bathymetric complexity was calculated using the "neighborhood statistics" option in Arcview 3.2. Arcview computes a standard deviation from all grid cells within a 1 kilometer radius around each cell. The results are displayed as standard deviations from the mean as this scale provides the best resolution for visualizing the location of high slope areas.

RESULTS AND DISCUSSION

Fish species, especially some rockfish species, have a very strong affinity to areas with a high relief (Yoklavich et al., 2000, 2002; Hixon et al., 1991; Hixon and Tissot, 1992; Field et al., 2002; Starr, 1998; and Williams and Ralston, 2002). Calculating the variability in bathymetry for a given area can provide a rough estimate of bottom rugosity on a scale of km. Smaller pinnacles may not be distinguished at this scale, but the large physical characteristics, such as the edge between the continental shelf and slope, canyons, and seamounts, will be displayed. The variable depth of the continental shelf break can be estimated using these maps. North of Cordell Bank NMS, the break occurs around 300 meters, within Cordell Bank and Gulf of the Farallones NMS, it is around 200 meters depth, north of Monterey Bay it becomes shallower at 150 meters, and inside Monterey Bay and to the south, the break is as shallow as 100 meters.

To determine the importance of bathymetric complexity to the formation of fish abundance, an analysis of variance was run to test for significant differences in bathymetric complexity between site groups for CDF&G recreational hook and line, NMFS shelf trawl, and NMFS slope trawl catches (see individual sections for results).

Subsection 2.1.1: ASSEMBLAGE ANALYSES

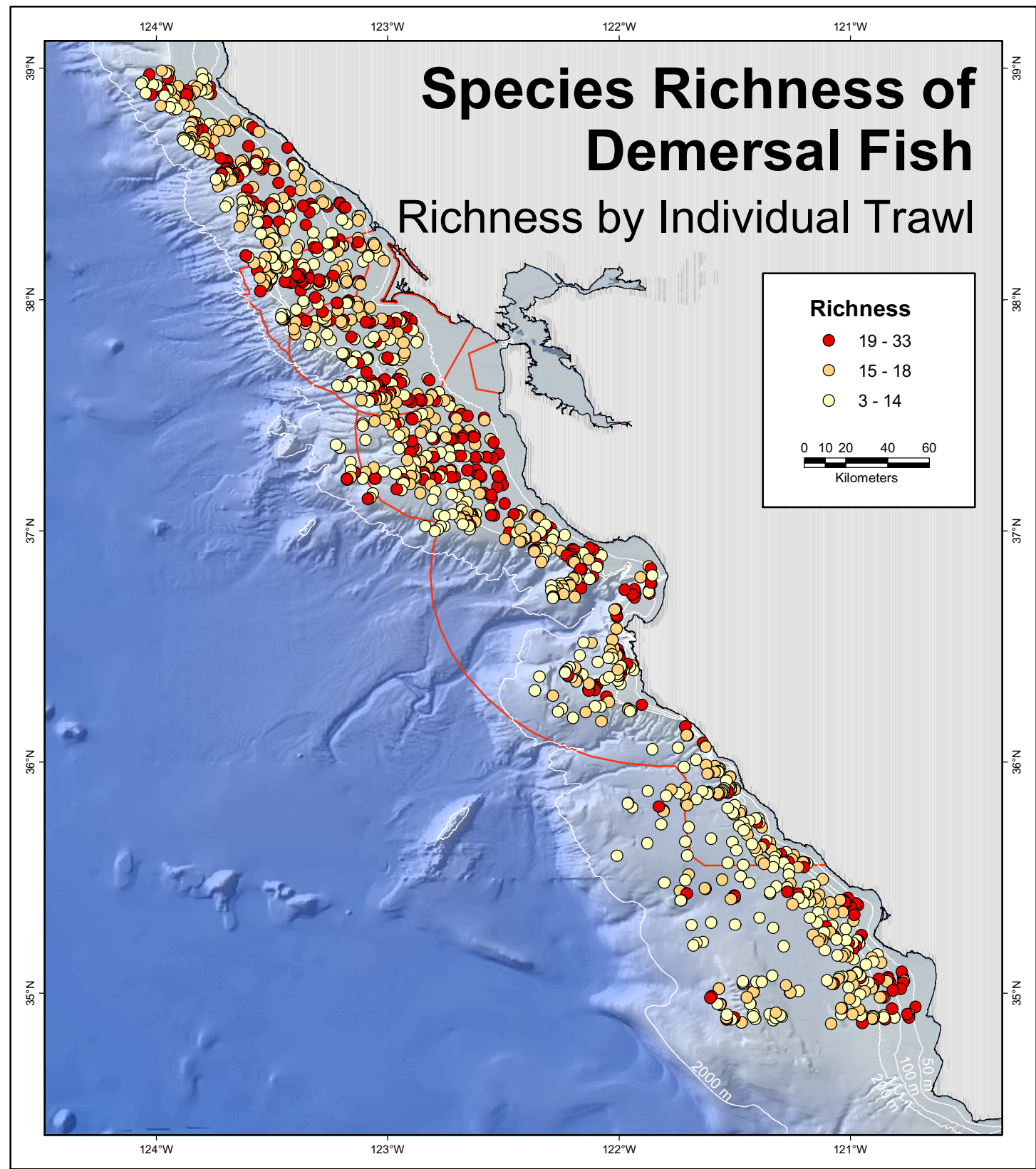


Figure 11. Species richness of individual NMFS shelf and slope trawls.

ABOUT THESE MAPS

Species richness of demersal fish was calculated for NMFS fish trawls (shelf and slope) conducted at depths between 50 and 1280 meters. The mean number of fish species recorded for trawls (\pm standard deviation) was 16 ± 5 . Species richness results are displayed for individual trawls (Figure 11), as well as mean richness for 5' grid cells (Figure 12). There appear to be three trawl areas with consistently high species richness: NW of Point Año Nuevo, SW of Morro Bay, and near the center of Cordell Bank NMS. In addition, there are smaller clusters within all three national marine sanctuaries. This map can be used to identify hot spots of demersal fish biodiversity.

DATA SOURCES

Richness estimates were derived from 1,336 NMFS (AKFSC and NWFSC) shelf (pp. 26) and slope (pp. 28) trawls conducted between 50-1280 meters depth during June-November every third year from 1977-2001. For details on the trawl methods see Lauth (2001), Shaw et al. (2000), Turk et al. (2001), and Williams and Ralston (2002). All fish identified to the species level were included (230 species).

METHODS

Richness is defined as the number of fish species present at a given location. To calculate richness, data were tabulated to determine the number of species caught in each trawl. Although there was a significant positive relationship between effort (calculated as distance fished \times net width) and species richness ($p < 0.0002$), this accounted for a very small percentage of the variability in the data set (adjusted $r^2 = .01$). Therefore, raw values of species richness for each trawl were used for this analysis. Trawls are only possible along relatively flat bottom areas with a minor incline, and no data were available for rocky, highly sloped areas. In addition, the NMFS data did not include trawls conducted in water less than 50 meters deep, therefore, shallow water sites are not represented with these results.

Figure 11 is useful for identifying actual trends in space, as well as identifying where the trawls occurred. Species richness results were organized into three equally sized groups representing the lowest, middle, and highest third of richness values. It is also useful to consider the mean richness for a small area. Therefore, mean richness and its deviation (how variable it is) was calculated for 5' grid cells throughout the study area (Figure 12). Cells with no deviation contained only one trawl. Cells that document high species richness, with low deviation, represent an area with consistently high species richness. Cell size was determined by minimizing the number of cells containing only one measurement yet retaining a reasonable spatial resolution of the cells. This also was the cell size used for integration with marine bird results. Species richness in cells is also presented in three equal sized groups as this best represents differences

in measurements between cells and facilitates comparisons between maps. Since the placement of the grids is arbitrary, the results will in-part depend on where the grid falls. An analysis comparing three different grid placements was conducted. It was determined that the placement of the grids had minimal influence on the results.

RESULTS AND DISCUSSION

The mean (\pm standard deviation) number of fish species recorded for a demersal trawl was 16 ± 5 , and ranged from 1 to 33. There are large areas with high species richness directly west and north of Point Año Nuevo, between the 50 and 100 m contour lines as well as west and south of Morro Bay between 50 and 200 M depth. There are smaller hot spots within Cordell Bank NMS, between 100 and 200 meters, as well as along the 200 meter contour in four locations: north of Cordell Bank NMS, just north of the southern Gulf of the Farallones NMS boundary, north of Monterey Bay and in southern Monterey Bay (Figure 11). For all trawls, there was a significant negative relationship between richness and depth, and a significant positive relationship between richness and latitude. However, neither of these relationships explained much of the variance ($r^2 = 0.04$, $p < 0.0001$ for depth; and $r^2 = 0.005$, $p < 0.004$ for latitude, $N = 1336$).

Many fish species are associated with near-shore areas, and were not included in this analysis due to the absence of NMFS trawls in shallow water areas. Other analyses in shallow water can provide a comparison to these results. Laidig (Pers Comm NMFS) has completed underwater scuba surveys to determine the presence of fish on kelp beds near Sonoma and Monterey. Average richness recorded on 43 dives in Sonoma was 5 ± 3 (range of 1 to 15), and 15 ± 4 on 9 dives in Monterey (range of 9 to 21). California Department of Fish and Game recreational fishing trips targeting rockfish (pp. 23) can also be used to determine approximate fish richness. Without effort information on angler hours, the utility of mapping richness is questionable. However, the mean richness recorded was 7 ± 4 (range of 1 to 21). The estimate of richness for near-shore areas from CDF&G trawls is lower than those measured with the NMFS shelf and slope trawl data, but the difference could be due to fishing method (hook and line vs. trawl) and is only mentioned as anecdotal validation. There was a large difference in the number of species observed in Sonoma and Monterey by Laidig, providing an example of the variability that can be experienced in kelp areas. Managers interested in protecting biodiversity of demersal fish could use this information in combination with the other assemblage analysis to address various management strategies. Cells with high species richness and low deviation could be used to identify potentially important areas which deserve further investigation.

Subsection 2.1.1: ASSEMBLAGE ANALYSES

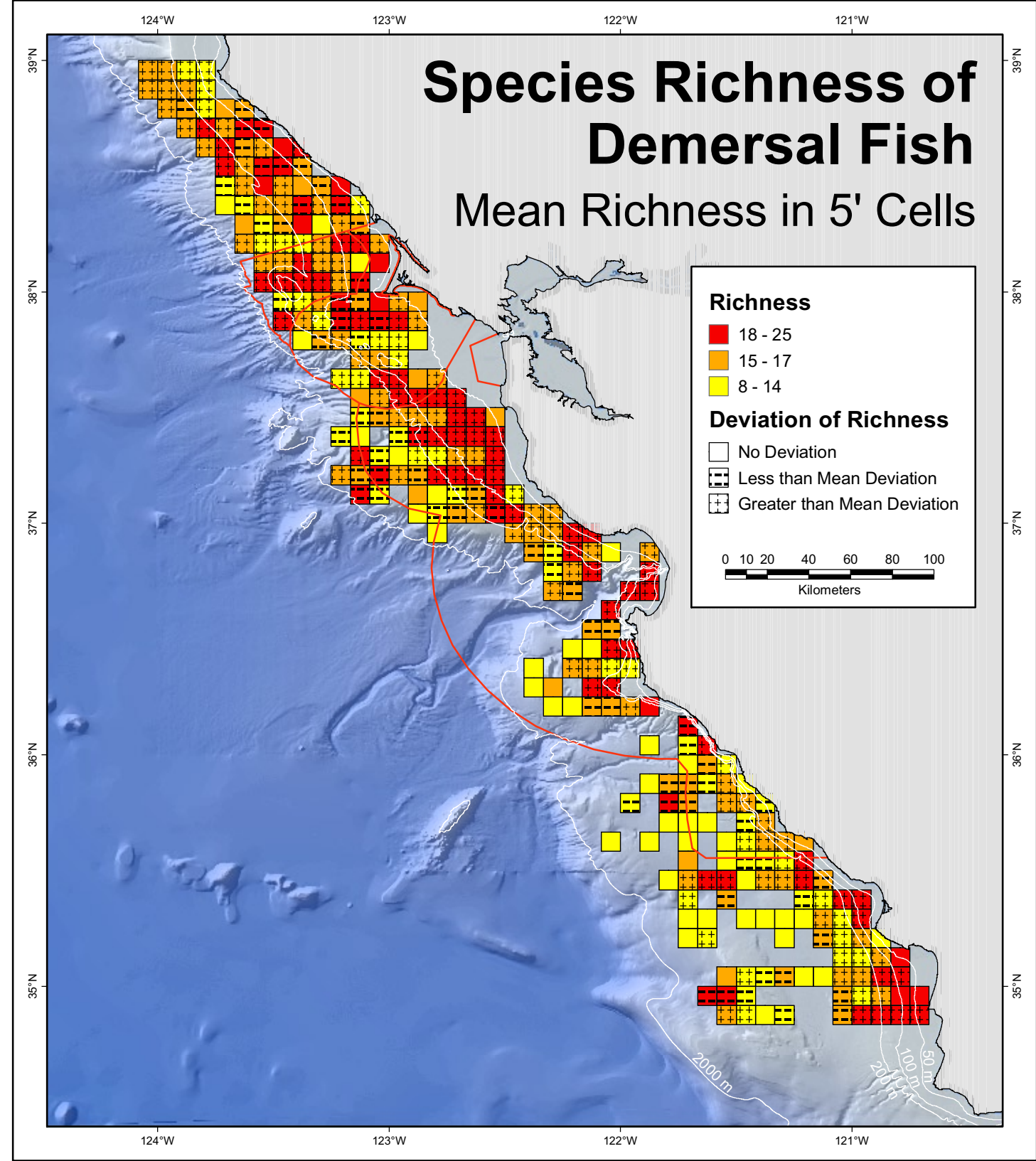


Figure 12. Mean species richness of NMFS shelf and slope trawls for 5' grid cells. The deviation is shown as an overlay to provide an indication of the variability in results for each grid cell.

Subsection 2.1.1: ASSEMBLAGE ANALYSES

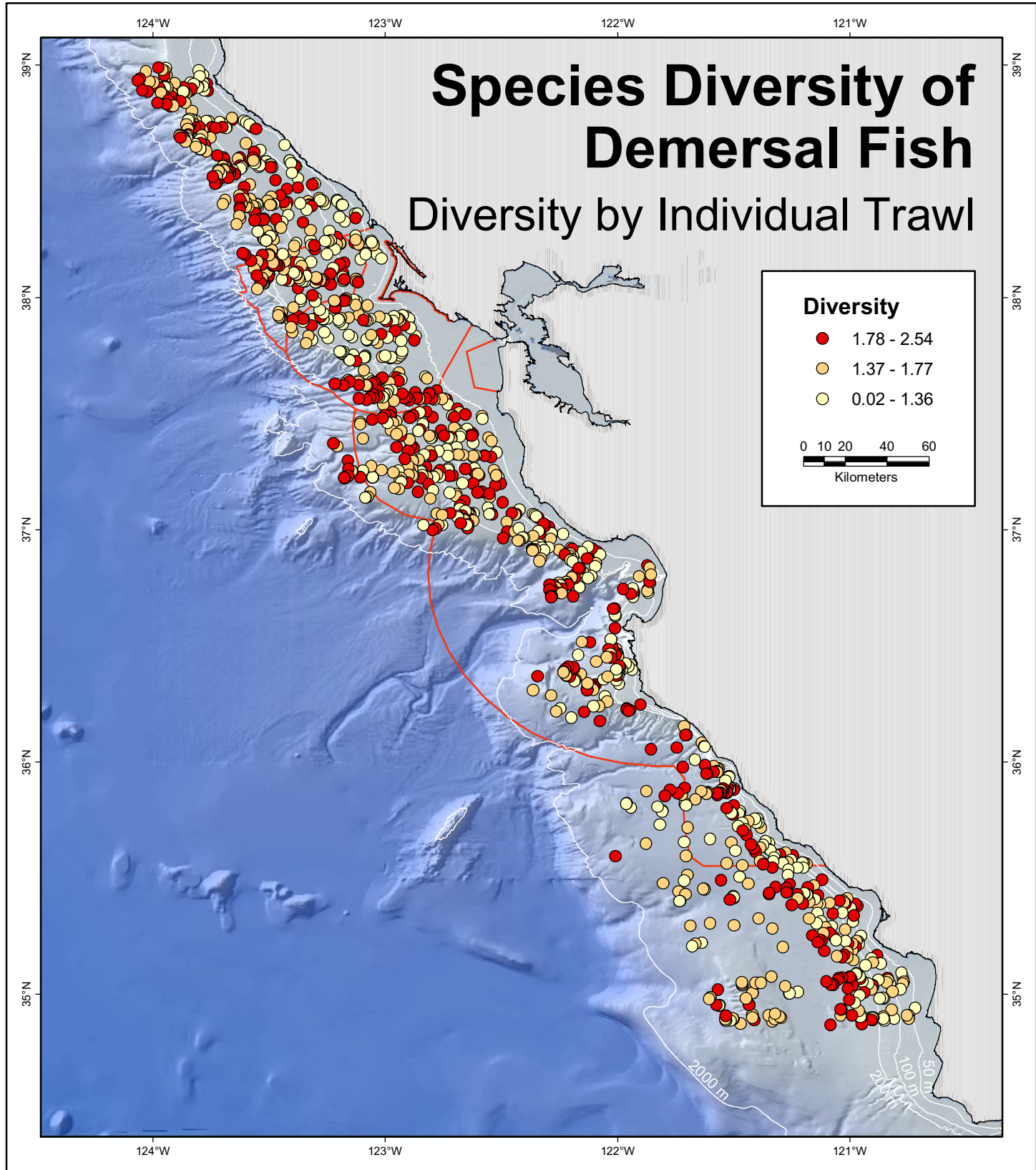


Figure 13. Species diversity of individual NMFS shelf and slope trawls.

ABOUT THESE MAPS

Species diversity of demersal fish was calculated for NMFS trawls on the shelf and slope at depths between 50 and 1280 meters. The mean diversity recorded for trawls (\pm standard deviation) was 1.5 ± 0.5 . Species diversity results are displayed for individual trawls (Figure 13), as well as mean diversity for 5' grid cells (Figure 14). The largest cluster of high species diversity trawls is found 20 km north and south of the border between Monterey Bay NMS and Gulf of the Farallones NMS. Smaller clusters of high diversity values are present in the northwest corner of Cordell Bank NMS and to the north and south of the NMS boundaries in waters slightly deeper than the 200 meter contour line.

DATA SOURCES

Diversity estimates were derived from 1,336 NMFS (AKFSC and NWFSC) shelf (pp. 26) and slope (pp. 28) trawls conducted between 50-1280 meters depth during June-November every third year from 1977-2001. For details on the trawl methods see Lauth (2001), Shaw et al. (2000), Turk et al. (2001), and Williams and Ralston (2002). All fish identified to the species level were included (230 species).

METHODS

Diversity reflects the distribution of species' abundance within a trawl. For example, a trawl dominated by one species would have a low diversity, while a trawl with an even number of all species would have a high diversity (see Figure 78, pp. 124). Since diversity is dependent on the abundance of species, fish caught in a trawl which were not given an estimate of abundance, or were not identified to species, were eliminated from the analysis. The Shannon index (H') was calculated for each NMFS shelf and slope trawl based on the following equation:

$$H' = - \sum_{i=1}^S \left[\left(\frac{n_i}{n} \right) \ln \left(\frac{n_i}{n} \right) \right]$$

Where S is the number of species, n_i is the number of individuals found of species i , and n is the total number of individuals (Shannon and Weaver, 1949). Although there was a significant positive relationship between effort (calculated as distance fished x net width) and species diversity ($p < 0.0001$), this accounted for a very small percentage of the variability in the data set (adjusted $r^2 = .06$). Therefore, raw values of species diversity for each trawl were used for this analysis. Trawls are only possible along relatively flat bottom areas with a minor incline, and no data were available for rocky, highly sloped areas. In addition, the NMFS data did not include trawls conducted in water less than 50 m deep, therefore, shallow water sites are not represented with these results. Figure 13 is useful for identifying actual trends in space, as well as identifying where effort occurred. For this figure, species diversity results were

divided into 3 equal sized groups representing the lowest, middle, and highest third of diversity values.

It is also useful to consider the mean diversity for a small area. Therefore, mean diversity and its deviation (how variable it is) was calculated for all trawls within 5' grid cells throughout the study area (Figure 14). Cells with no deviation contained only one trawl. Cells that document high species diversity, with low deviation, represent an area with consistently high species diversity. Cell size was determined by minimizing the number of cells containing only one measurement, yet retaining a reasonable spatial resolution of the cells. In addition, this was also the cell size used for integration with marine bird analyses (section 3). Species diversity in cells is also presented in 3 equally sized groups. Since the placement of the grids is arbitrary, the results will in-part depend on where the grid falls. An analysis comparing three different grid placements was conducted, and it was determined that the placement of the grids had minimal influence on the results.

RESULTS AND DISCUSSION

The mean (\pm standard deviation) diversity recorded for a demersal trawl was 1.5 ± 0.5 , with range from 0.02 to 2.54. The largest cluster of high species diversity straddles the boundary between Monterey Bay NMS and Gulf of the Farallones NMS. Fifty-eight (13%) of the high diversity trawls are located within 20 kilometers of this boundary. The western edge of this area contains consistently high diversity trawls (low deviation). A smaller cluster of high diversity trawls is present in the northwest corner of Cordell Bank NMS, extending approximately 6 kilometers north of the current boundary. Within this cluster, 95% of the trawls are classified as either medium or high diversity. In addition, there are two lines of trawls with high species diversity located slightly deeper than the 200 meter contour line: one north of Cordell Bank NMS to the northern edge of the study area, and the other from Lopez Point south to the southern edge of the study area. A large portion of these trawls are outside sanctuary boundaries. For all trawls, there was no significant relationship between diversity and latitude ($r^2 = 0.0$, $p = 0.57$, $N = 1336$). There was a significant relationship between diversity and depth; however, it did not explain much of the variance in the data ($r^2 = 0.04$, $p < 0.0001$, $N = 1336$). Many fish species associated with near-shore, or high relief areas, were not included in this analysis due to the absence of NMFS trawls in these areas. California Department of Fish and Game recreational fishing trips (pp. 23) were often located in near-shore or high relief areas, and can be used to determine approximate fish diversity over these habitats. The mean fish diversity recorded for recreational hook and line locations was 1.3 ± 0.6 (range of 0 to 2.5). This estimate of diversity is similar to those measured with the NMFS shelf and slope trawl data; however, since the collection method was different, no statisti-

Subsection 2.1.1: ASSEMBLAGE ANALYSES

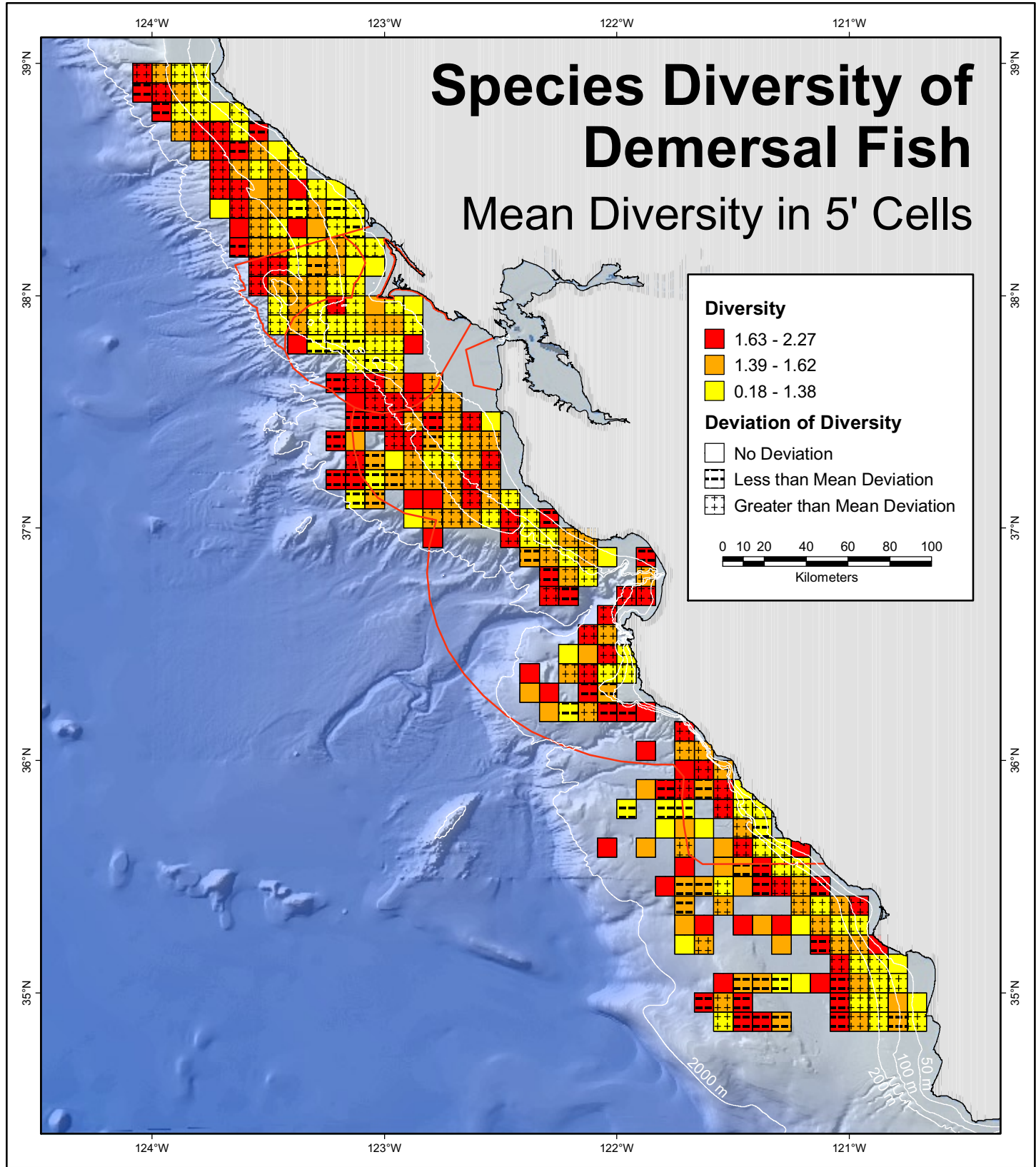
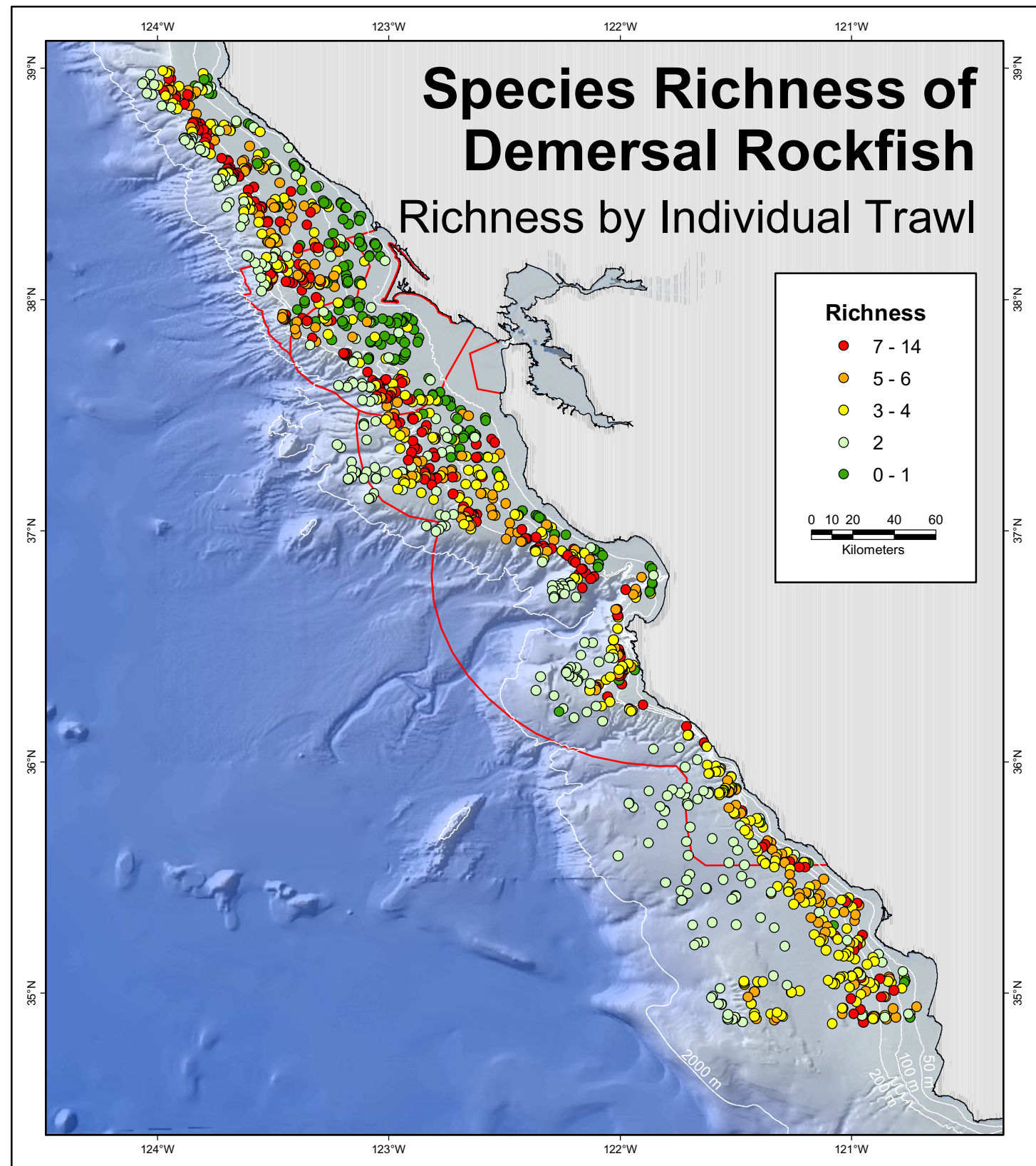


Figure 14. Mean species diversity of NMFS shelf and slope trawls for 5' grid cells. The deviation is shown as an overlay to provide an indication of the variability in results for each grid cell.

cal comparisons can be completed and these results are only intended as anecdotal validation.

Trawls with high species diversity are not necessarily trawls with high richness. Since diversity takes into account the number of fish of each species found, areas with one or two abundant species have a lower diversity than areas with less fish species, but an even distribution. High richness trawls are slightly shallower than high diversity trawls suggesting that the trawls deeper than 200 meters have fewer species, but a more even distribution. The presence of a high diversity area along the boundary between Gulf of the Farallones and Monterey Bay Sanctuaries defines an area of biological significance for demersal fish. In addition, there are lines of high species diversity north and south of the current boundaries deeper than the 200 meter contour. The trawls located on top of Santa Lucia Bank had medium to high species diversity, and represent a large expanse of deep habitat not within sanctuary boundaries. This area, combined with existing NMS shelf and slope areas, appears important to groundfish as indicated by high diversity patterns. Managers interested in protecting biodiversity of demersal fish can use this information in combination with the other assemblage analysis results to address various management strategies.

Subsection 2.1.1: ASSEMBLAGE ANALYSES



ABOUT THIS MAP

Species richness of demersal rockfishes was calculated from NMFS shelf and slope trawls (Figure 15). The information on this map identifies areas with a high number of rockfish species. Values were not influenced by latitude, but were highly influenced by depth. The highest rockfish richness values were observed along the edge between the shelf and slope, emphasizing the importance of these areas to rockfish. Sanctuary boundaries now include more than 500 square kilometers of this edge area (between 200 and 300 meters depth), with 75% of this area within Monterey Bay NMS. The area south of Monterey Bay NMS to the edge of the study area contains another 500 square kilometers of habitat between 200 and 300 meters.

DATA SOURCES

Data were derived from 1,336 NMFS (AKFSC and NWFSC) shelf (pp. 26) and slope (pp. 28) trawls conducted between 50-1280 meters depth during June-November from 1977-2001. For details on the trawl methods see Lauth (2001), Shaw et al. (2000), Turk et al. (2001), and Williams and Ralston (2002). All rockfish identified to the species level were included (48 species).

METHODS

Species richness is defined as the number of fish species present at a given location. To calculate rockfish richness, data were tabulated to determine the number of rockfish species *Sebastes* or *Sebastolobus* present in each trawl. There was no significant relationship between trawl effort (distance fished x net width) and species richness ($N=1336$, $F=1.3$, $p=0.26$), so raw values of species richness for each trawl were used for this analysis. Trawls are only possible along relatively flat bottom areas. No trawls were conducted over rocky, high relief areas or areas in water less than 50 m deep, therefore, some potentially important sites were not considered in these analyses.

RESULTS AND DISCUSSION

The mean (\pm standard deviation) number of rockfish species recorded for a demersal trawl was 4 ± 3 , with a range from 0 to 14. The results show that bathymetry has a strong influence on rockfish species richness. The lowest rockfish richness is found in the shallower (but still >50 m) and deeper waters. A band of high rockfish richness is located around 200-300 meters depth and parallels the edge between the continental shelf and slope. For all trawls, there was a significant non-linear relationship between richness and depth (Figure 16, $F=166$, $p<0.0001$), and no significant relationship between richness and latitude ($F=2.1$, $p=0.15$). Almost all trawls on the deep slope (deeper than 600 meters) contain the same two rockfish species (shortspine and longspine thornyheads). It is important to note that many rockfish species are associated with kelp beds

or high relief areas which were not included in this analysis. Other analyses conducted in these habitats can provide a comparison to these results. Tom Laidig (pers. comm. NMFS) has conducted scuba surveys to determine the presence of fish on kelp beds near Sonoma and Monterey in California. Average rockfish richness recorded on 43 dives in Sonoma, between 1983 and 1995, was 5 ± 2 (range of 0 to 9), and 8 ± 2 on 9 dives in Monterey (range of 5 to 12). California Department of Fish and Game recreational fishing trips targeting rockfish (pp. 23) can also be used to determine approximate rockfish richness. However, without fishing effort information, the utility of mapping the richness from recreational fishing data is questionable. Average rockfish richness recorded per location/trip combination was 6 ± 2 (range of 0 to 12). The estimate of rockfish richness for near-shore areas from CDF&G trawls is similar to those measured with the NMFS shelf and slope trawl data, but since the capture method was different, these results should only be used as an anecdotal validation.

The results of this analysis illustrate the importance of the edge between shelf and slope areas. This result supports that of Williams and Ralston (2002), who found highest rockfish richness between 200 to 250 meters depth using NMFS shelf data for California and Oregon.

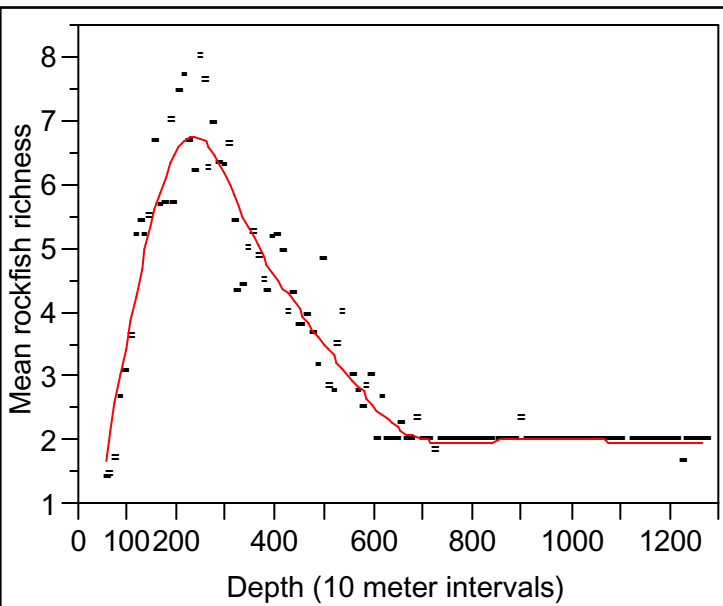


Figure 16. The relationship between depth and rockfish richness showing mean rockfish richness (for 10 meter depth intervals between 50-1300 meters). The relationship was fit with a smoothing spline, $\lambda = 1,000,000$.

Figure 15. Species richness of rockfish from individual NMFS shelf and slope trawls.

Subsection 2.1.1: ASSEMBLAGE ANALYSES

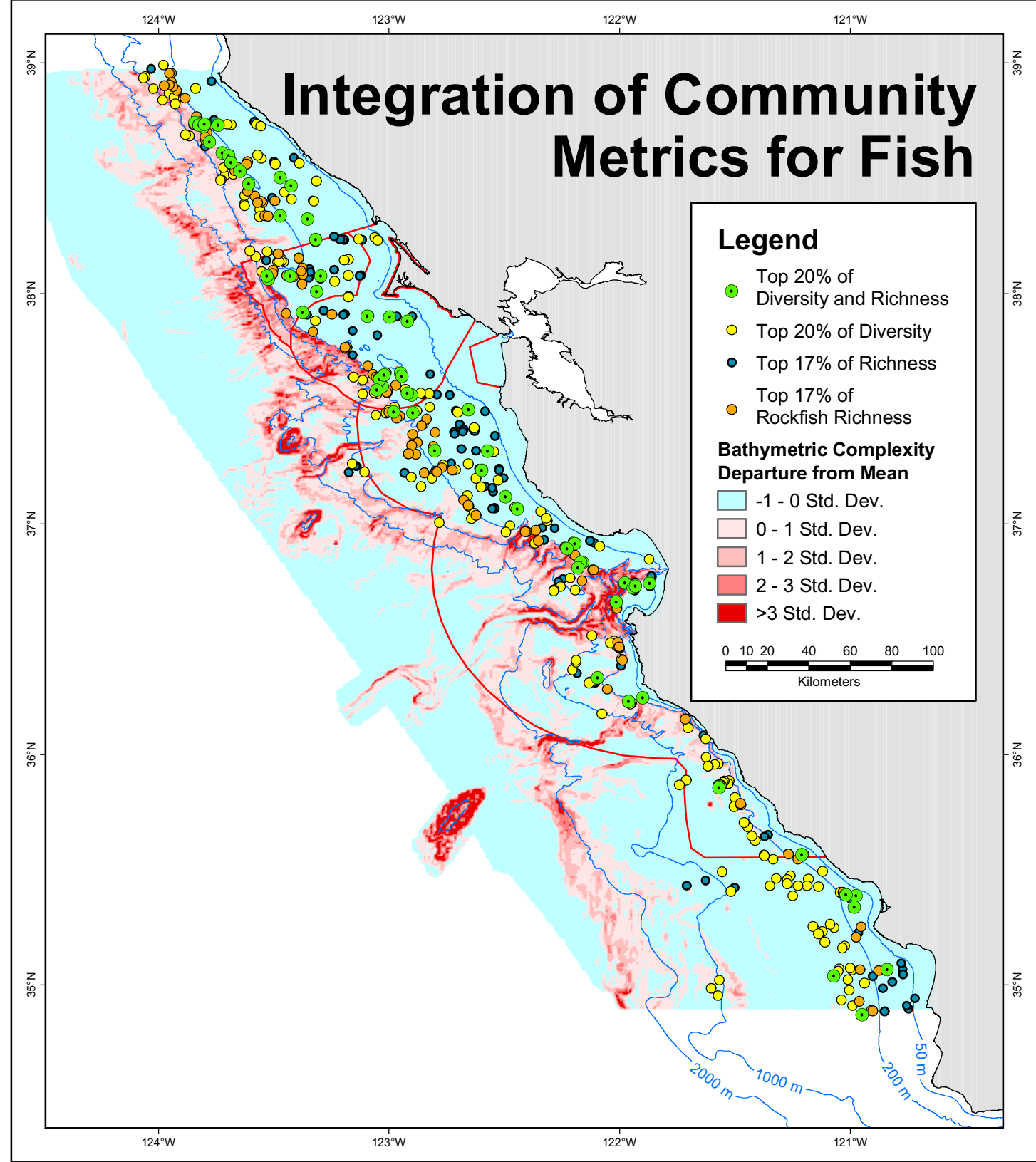


Figure 17. NMFS shelf and slope trawls with the highest species diversity, species richness, and rockfish richness are mapped. The underlying map illustrates the bathymetric complexity of the study area and can be used to identify the shelf break.

ABOUT THIS MAP

The last three sections showing species diversity, species richness, and rockfish richness have provided results relevant to managing resources. Figure 17 illustrates the overlay of the top 17-20% of trawls for high species diversity, species richness, or rockfish richness. The background of the map shows the bathymetric complexity from page 16. The overlay of the points provides visual representation of the results.

DATA SOURCES

Diversity, richness, and rockfish richness estimates were derived from 1,336 NMFS (AKFSC and NWFSC) shelf (pp. 26) and slope (pp. 28) trawls conducted between 50-1280 meters depth during June-November from 1977-2001. For details on the trawl methods see Lauth (2001), Shaw et al. (2000), Turk et al. (2001), and Williams and Ralston (2002).

METHODS

Methods for calculating diversity, richness, and rockfish richness are detailed in each section. The top 20% of trawls for diversity were extracted and mapped. Ideally, the top 20% of trawls for overall species richness and rockfish richness would be provided; however, since richness is discrete and not continuous, either 17% (21+ species) or 23% (20+ species) could be mapped. The trawls which were within the top 20% for both richness and diversity are distinguished.

RESULTS AND DISCUSSION

Richness calculates the number of fish species present in each trawl, while diversity takes into account the abundance of fish species as well. Diversity and richness are correlated ($r^2=0.06$), but trawls with high diversity are not necessarily trawls with high richness. Trawls which were high in overall richness and diversity were distinguished, and show areas important to demersal fish. A cluster of trawls with high diversity and high richness straddle the boundary between Gulf of the Farallones and Monterey Bay NMS, as well as along the 200 meter contour north of Cordell Bank NMS. Small clusters of high diversity and high richness trawls are present within each sanctuary. Depth varied between the three community metrics, with high richness, rockfish richness, and diversity progressing from shallow to deep. The mean depth for trawls with the top 17% of rockfish richness was 221 ± 87 , with 43% of the trawls between 200 and 300 meters depth. Showing these trawls reemphasizes the interaction between rockfish richness and the edge of the continental shelf. The trawls with high species richness show much more variability with depth (mean depth 212 ± 225 meters), but 64% of them are in water less than 200 meters deep. The trawls with high species diversity were deeper (mean depth 372 ± 289 meters), with 52% of them greater than 300 meters depth. Overall, the trawls with high diversity were deeper than the trawls with high richness.

A good example of this split by depth can be found south of the Monterey Bay NMS. This suggests that trawls with high species richness found just east of the 200 meter contour are dominated by a few influential species. Conversely, the areas of high diversity just west of the 200 meter contour might have one or two fewer species, but overall the species are evenly distributed.

Results from the assemblage analyses were significantly tied to depth; therefore, maps show bands of similar sites along depth contours and do not delineate areas important to demersal fish. Conversely, the results from the community metrics do delineate hot spots. Results are limited by collection method since rocky, highly sloped, or shallow (less than 50 meters depth) areas were not sampled. Managers could use the interaction of the community metrics to decide on proper management strategies. For example, management is often tasked with protecting biodiversity, and is therefore interested in delineating areas that contain the highest number of species. However, if an area is high in richness, but is dominated by one economically important species, protecting this area could contribute to resource use conflicts. The interplay between diversity and richness should be carefully evaluated.

Subsection 2.1.1: ASSEMBLAGE ANALYSES

ABOUT THESE ANALYSES

Managers have recently begun to understand the importance of studying entire ecosystems rather than looking at each species individually. This study took a first step in clarifying multi-species interactions by determining which species tended to be caught together, and where. Multivariate statistics were used to analyze fish species assemblages on the scale of the recreational fishery over marine habitats off central California. This data set, while fishery dependent, includes demersal, as well as midwater species captured on variable habitats, including rock, mud, and sand. Some species and habitats in this analysis are not covered with the other data sets in this study, and therefore provide complimentary information. Twenty-seven fish species were grouped into seven species assemblages (Figure 18), and 4,357 trip/location combinations were grouped into eight site groups (Table 1). Unfortunately, due to the nature of the data set (see methods), exact fishing locations could not be mapped. Therefore, the mean depth associated with each site group is provided in conjunction with a map showing the fishing locations in 2.5 minute grids, which were color coded according to the average depth of the fishing trips within the grid cell. The two analyses mentioned above provide information on species which were caught together, and locations with similar catch. Combining the two results was the challenge. The average frequency of occurrence of species assemblages (percent occurrence calculated for each species and then averaged for each fish assemblage) within each site group was calculated to analyze the interaction between the species assemblages and site groups (Table 2). As with all data sets in this assessment, the most significant result was the effect of depth. This supports previous work done by Williams and Ralston (2002), Sullivan (1995), Field et al. (2002), Gabriel and Tyler (1980), and Matthews and Richards (1991), who found bathymetry to be an important factor in defining fish assemblages. All attempts to isolate and remove the effects of depth in order to determine secondary effects were unsuccessful. Certainly, secondary effects exist, but at the scale of this study they were not discernible. Through this analysis, a large amount of information has been condensed to assemblages of co-occurring species, as well as groups of similar locations. A map is provided to visually portray the spatial arrangement of the results.

DATA SOURCES

Data from 2167 commercial passenger fishing vessels, fishing for rockfish or lingcod, using hook and line, were collected during all months between 1987 and 1998 at depths between 2-360 meters. Each trip visited between 1 and 8 locations, with each trip/location combination considered a unique site. For this data set, effort was not provided, and therefore only presence/absence was analyzed at each trip/location combination. The data set contained information on 103 fish species, but after removal of rare species, the data matrix used for classification contained information on 27 fish species at 4357 trip/location combinations. A list of common and scientific names of the species included in the analysis is available on the accompanying CD-ROM. To protect individual fishing locations as requested by the CDF&G, results are presented in 2.5 minute grids. For more information on the data collection process see Wilson-Vandenberg et al. (1996).

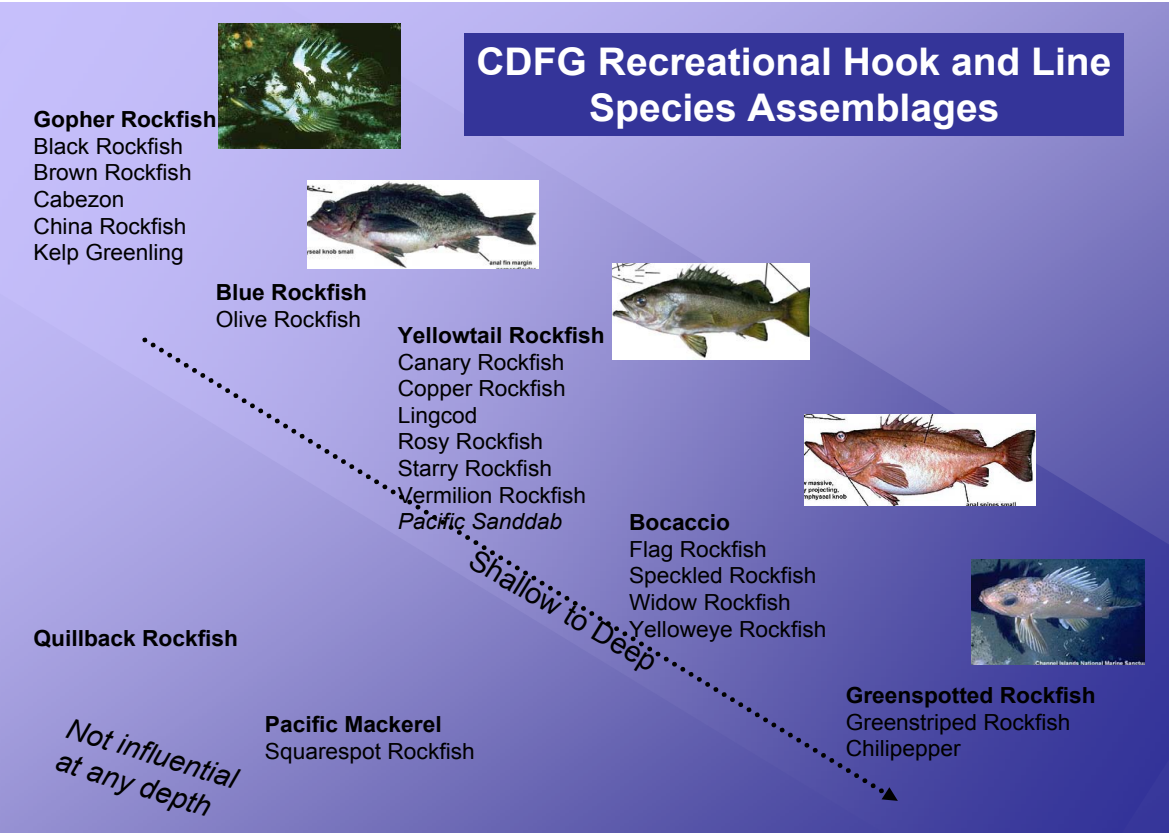


Figure 18. Species assemblage results for the recreational data. Assemblages are named for the most influential species in each group. Assemblages are arranged from shallow to deep, unless they are influential at all or none of the depths. The assemblages that were not influential at any depth were composed of relatively rare species, making depth associations indiscernible given the methodology for defining “influential” assemblages. Non-italicized species were consistently placed into the same species assemblage >80% of the time; italicized species tended to roam into other assemblages with random sampling.

the results compared for persistence and precision. Additionally, the data from 1993 to 1998 was analyzed separately to determine if current conditions have changed enough to affect the resultant species assemblages. Conditions that could have changed through time include: abiotic shifts, such as decadal shifts in water temperature; biotic shifts, such as depletion of key species; and effort shifts, such as fishing farther offshore. To determine which species groups were influential in forming the site groups, the average frequency of occurrence for species assemblages in each site group was calculated. Species assemblages were considered influential if, on average, species were present in 25% of the trip/location combinations in a site group. The mean depth associated with each site group is provided in conjunction with a map showing the fishing locations in 2.5 minute grids, and color coded according to the average depth of the fishing trips within the grid cell. Two-way analyses of variance (ANOVA) were conducted with depth (pp. 37 Figure 32) and latitude, sediment (pp. 38 Figure 33), and bathymetric complexity (pp. 16 Figure 10) to determine if any of these factors have an influence on the site group results at the scale of this analysis.

RESULTS AND DISCUSSION

Species Assemblages (Objective A)

Seven species assemblages were differentiated from the recreational data, and named according to the most influential species (Figure 18). When the data from 1993-1998 were analyzed separately, there were two minor changes: the yellowtail rockfish assemblage split into two assemblages, and squarespot rockfish moved from the Pacific mackerel assemblage to the bocaccio assemblage. Overall, the species assemblages delineated were surprisingly robust; almost all fish were consistently placed in the same assemblages for more than 80% of the random runs, providing confidence in the stability of the assemblages. Running the modified bootstrap technique can provide an estimate of the precision of results, but verifying the accuracy of the results is more difficult. Comparisons of the results with past studies can give feedback on the accuracy of the results. Assemblages are not static, and may modify in response to environmental conditions, such as warm or cold conditions (see CD-ROM for changes in species assemblages in response to water temperature or season).

Love et al. (2002) provides a summary of rockfish habitat requirements and species co-occurrences. The gopher rockfish and blue rockfish assemblages are supported by Love et al. (2002) as the species in each assemblage are described as having the same habitat or co-occurring. In addition, Mason (1995) looked at the recreational logbook and described a shallow rockfish assemblage composed of blue, black, brown, gopher, and olive rockfishes, all found within the gopher and blue assemblages described in this study. The greenspotted assemblage from this analysis is not necessarily intuitive. Greenspotted and greenstriped can both be found on mud near rocks (Love et al., 2002), but this is also a characteristic of some of bocaccio and yellowtail assemblage species (Love et al., 2002). Mason (1995) designated a deepwater red rockfish assemblage that included greenspotted, greenstriped, chilipepper, and bocaccio, which provides some support to the greenspotted assemblage of this study. Flag rockfish is an example of a species co-occurrence mentioned in Love et al. (2002) that is not supported here. Flag rockfish was placed in the bocaccio assemblage in this study, but

Subsection 2.1.1: ASSEMBLAGE ANALYSES

according to Love et al. (2002), flag is often found with species from the yellowtail rockfish assemblage. Within the modified bootstrapping procedure, flag rockfish was placed with the Bocaccio assemblage 78% of the time, and with the yellowtail rockfish assemblage only 28% of the time, supporting its placement in this analysis.

The results comply with the large scale assemblages designated by NMFS: near-shore, shelf, and slope species groups (NMFS). All of the rockfish in each species assemblage from this study come from the same NMFS group, except for the yellowtail assemblage, which contains four species designated as “shelf” and one species designated as “near-shore”. Williams and Ralston (2002) grouped rockfish from the NMFS shelf trawl data into eight groups. While their assemblages differ from this study's results, of the eleven species analyzed in both data sets, species from the bocaccio and greenspotted rockfish assemblages are placed together, and species from the gopher rockfish and yellowtail rockfish assemblages are placed together. Comparison of the results from this study with results based on trawl (NMFS; Williams and Ralston, 2002; Gabriel and Tyler, 1980; Jay, 1996), or results from submersibles (Yoklavich et al., 2000, 2002; Hixon et al., 1991; Hixon and Tissot, 1992; Field et al., 2002), is difficult due to the species analyzed, the different habitats targeted, and the variable scale of the results. Matthews and Richards (1991) found different species assemblages over trawlable and untrawlable habitats, showing the effect targeting different environments can have on species assemblages. Scale is important since the recreational boat drifts over multiple habitats during a set, and fish from multiple habitats can be present in one trip/location combination. In addition, species assemblage results could also be confounded by ontogenetic habitat shifts because the sizes of the fish captured were not considered.

Site Groups (Objective B)

Eight site groups were identified from the 4,357 trip/location combinations (Table 1). To make interpretation easier, the site groups are named according to mean depth. Maps with the location of the site groupings in the 2.5 minute grid are hard to interpret

Site Group (Names based on depth)	N	Depth±SD (meters)
Group 26 meters	581	26 ± 13 ^a
Group 40 meters	688	40 ± 16 ^b
Group 44 meters	183	44 ± 27 ^b
Group 59 meters	235	59 ± 26 ^c
Group 64 meters	1,501	64 ± 18 ^d
Group 77 meters	207	77 ± 22 ^e
Group 98 meters	683	98 ± 21 ^f
Group 125 meters	279	125 ± 32 ^g

Table 1. Site group results for recreational data. The numbers of trip/location combinations associated with each group as well as average depth, ± standard deviation, are provided. Different letters signify a significant difference using Tukey’s pairwise comparison on log adjusted depth with overall alpha set at 0.001.

due to overlap of more than one group within the same cell. For example, within one grid cell on the southern side of Monterey Bay, the maximum depth fished ranged between 37 and 660 meters, and contained sites from all 8 cluster groups. Therefore, the mean depths fished ±SD are presented, which can be used in conjunction with Figure 19 to determine the approximate location of the site groups. Depth was the primary determinant of site groupings. All but two (groups 40 and 44) of the eight site clusters were significantly different in depth (see Table 1), suggesting that depth is highly influential in determining species distributions within the study area. The site groups we identified were similar to results of Sullivan (1995), who analyzed a subset of this same data to differentiate areas based on species composition. A direct comparison between Sullivan and this study is difficult because Sullivan describes his locations verbally using land identifiers, while this study describes locations by depth. The importance of depth in this ecosystem is not a new idea; many researchers have already commented on its influence (Williams and Ralston, 2002; Sullivan, 1995; Gabriel and Tyler, 1980; Field et al., 2002; Matthews and Richards, 1991). Latitude has also been described as having an influence on California fish species composition (Williams and Ralston, 2002; Horn and Allen, 1978; Sullivan, 1995), but for the area of this study, no latitudinal results were evident.

Interaction of Species and Sites (Objective C)

The interaction between site groups and species assemblages (i.e. the location of species assemblages) reemphasized the relationship between species and depth. Species assemblages which were influential in forming each site group are identified (Table 2). Site group 44 did not seem to be associated with any fish assemblages (none with a frequency of occurrence greater than 25). At this point, it is uncertain what factor caused the clustering of this group. For all of the trip/location combinations, on average 68 fish were caught. The average number of fish caught for group 44 was 12, suggesting that some outside factor, such as poor weather, was influencing catches at these sights.

Habitat Correlations (Objective D)

Other factors besides depth can have an impact on species assemblages. Examples include latitude (Horn and Allen, 1978; Sullivan, 1995), sediment type (Yoklavich et al., 2000, 2002; Field et al., 2002; Hixon et al., 1991; Hixon and Tissot, 1992), and substrate relief (see bathymetric complexity section pp. 16) (Yoklavich et al., 2000, 2002; Field et al., 2002). Unfortunately, since there were significant interactions present between all of these variables and depth, it could not be determined if the significance detected for these factors was due to this interaction with depth. Even though bathymetric complexity increases as depth increases, groups 44, 59, and 125 meters have a higher bathymetric complexity than the groups around them with similar depth. All attempts to remove depth and determine secondary influences on group designation were unsuccessful. The non-linear relationship between the fish species and depth made removal of depth impossible. While these other factors appear to have a decreased significance when compared to depth, more complex analyses exploring ways to remove the effects of depth and determine the relative significance of these factors may be completed in Phase II.

	Group 26 meters	Group 40 meters	Group 44 meters	Group 59 meters	Group 64 meters	Group 77 meters	Group 98 meters	Group 125 meters
Gopher Assemblage	0.36	0.23	0.14	0.09	0.09	0.01	0.01	0.00
Blue Assemblage	0.72	0.74	0.07	0.19	0.69	0.20	0.07	0.00
Yellowtail Assemblage	0.22	0.42	0.08	0.31	0.74	0.31	0.57	0.08
Bocaccio Assemblage	0.01	0.05	0.00	0.05	0.23	0.25	0.43	0.22
Greenspotted Assemblage	0.00	0.00	0.02	0.02	0.07	0.10	0.50	0.59
Pacific Mackerel Assemblage	0.02	0.07	0.13	0.07	0.12	0.17	0.09	0.06
Quillback	0.01	0.06	0.05	0.04	0.09	0.01	0.02	0.00

Table 2. Average frequency of occurrence of fish species assemblages (percent occurrence calculated for each species and then averaged for each fish assemblage) for each recreational site group. Numbers in bold represent influential species assemblages within that site group.

In conclusion, this analysis provides results showing species assemblages, site assemblages, and the location of species assemblages for the important near-shore, rocky environment. Understanding species assemblages and mapping their location provides important information for managers. For example, to include the most species assemblages, protecting an area that covers a large variation in depth may be more important than protecting an area that covers a large variation in latitude. The results of this analysis in conjunction with similar analyses on the three other data sets provides a fairly comprehensive overview of fish and macro-invertebrate species within the study area.

Subsection 2.1.1: ASSEMBLAGE ANALYSES

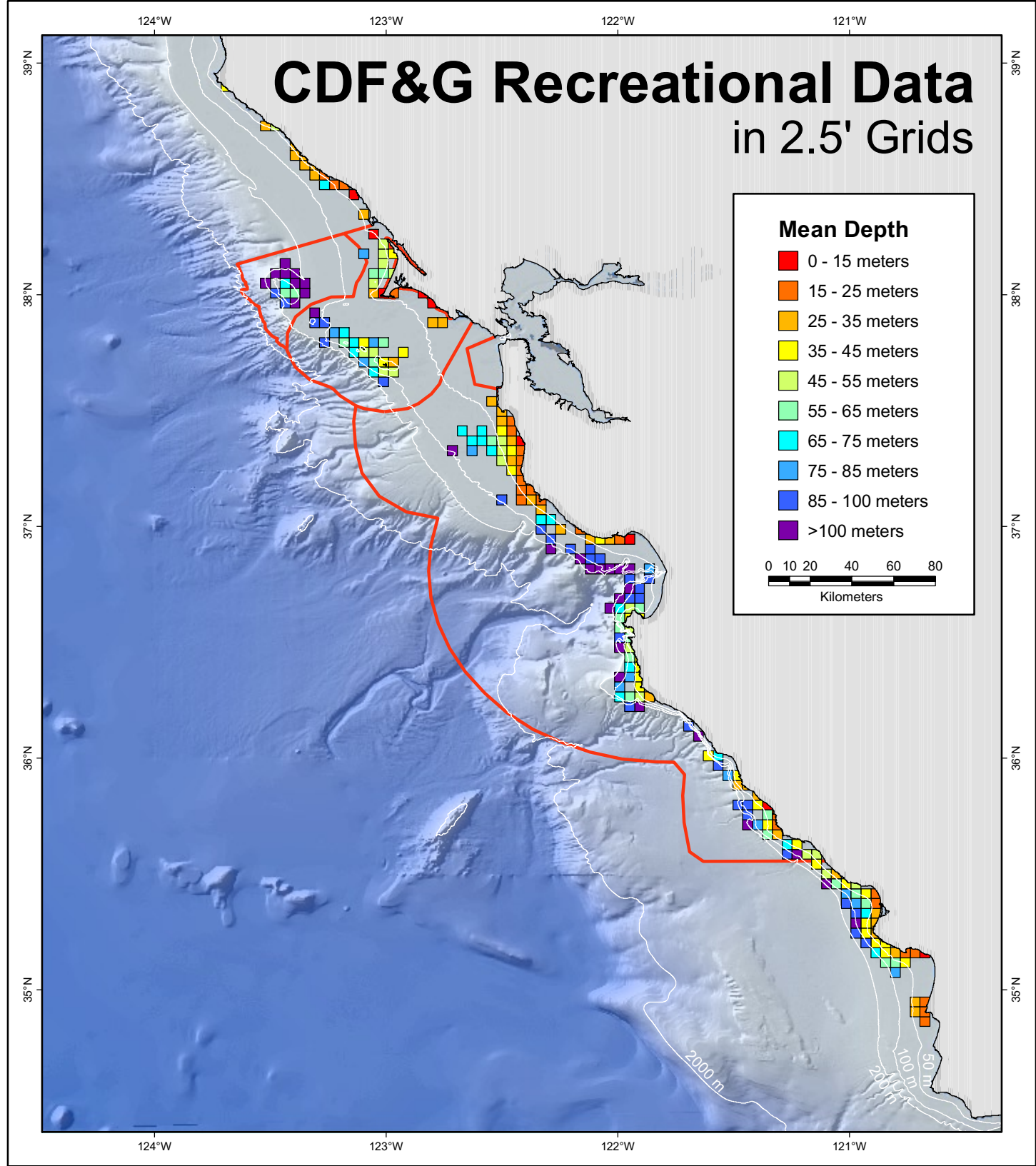


Figure 19. Location of CDF&G recreational fishing data in 2.5 minute grids which are color coded according to the average depth of the fishing trips within the grid cell. Lines showing the 50, 100, 200, and 2,000 depth contours are provided.

Subsection 2.1.1: ASSEMBLAGE ANALYSES

ABOUT THIS MAP

Recently managers and scientists have begun to understand the importance of studying communities of species rather than just managing by individual species. This study was an initial assessment aimed at determining which species tended to be caught together, and where. Multivariate statistics were used to analyze species assemblages over trawlable habitats of the continental shelf between 55 and 500 meters depth off California. For an introduction to the continental shelf ecosystem, see the *Ecological Linkages Report*. Sixty-one species were grouped into thirteen species assemblages (Figure 20), and 883 trawls grouped into eight site groups (Table 3, Figure 21). The average frequency of occurrence of species assemblages (percent occurrence calculated for each species and then averaged for each fish assemblage) within each site group was calculated to analyze the interaction between the species assemblages and site groups (Table 4). As with all data sets, the most significant result was the effect of depth on species assemblages. All attempts to isolate and remove the effects of depth in order to determine secondary effects were unsuccessful. Certainly secondary effects exist, but at the scale of this study, they were not discernible. Our results support previous results by Williams and Ralston (2002), Sullivan (1995), Field et al. (2002), Gabriel and Tyler (1980), and Matthews and Richards (1991), who found bathymetry to be an important factor in defining west coast demersal fish assemblages. Through this analysis, a large amount of information has been condensed to assemblages of co-occurring species, as well as groups of similar locations. A map is provided to visually portray the spatial arrangement of the results.

DATA SOURCES

Data from 883 fisheries independent research trawls (55-500 meters depth) were collected every third year, between 1977 and 2001, during the months of June-August. Gear included a nor'easter trawl (127 mm stretched-mesh body; 89 mm stretched-mesh codend; and 32 mm stretched-mesh codend liner) with a rubber bobbin roller which was trawled for 15-30 minutes on the bottom. Data was adjusted for effort and to meet statistical assumptions by dividing number of fish caught by the area covered and then log transforming. The data set contained information on 167 fish species, but after removal of rare species, the data matrix used for clustering contained only 58 fish and 3 invertebrate species. A list of common and scientific names of the species included in the analysis is available on the accompanying CD-ROM. Since each NMFS cruise hosted scientists with varying levels of expertise in invertebrate identification, NMFS scientists recommended that only well known/common invertebrate species be included in the analyses. Fish species assemblages were identical with and without the inclusion of invertebrates in the analysis. For more information on how the data were collected, including the site selection process and how it changed through time, see Shaw et al. (2000), Wilkins et al. (1998), and Zimmermann et al. (2001).

METHODS

The aim of the entire assemblage analysis was to increase our understanding of the biogeography of fishes and macro-invertebrates in relationship to their environment, and identify important areas or habitats. Four of the five main objectives were addressed in this analysis:

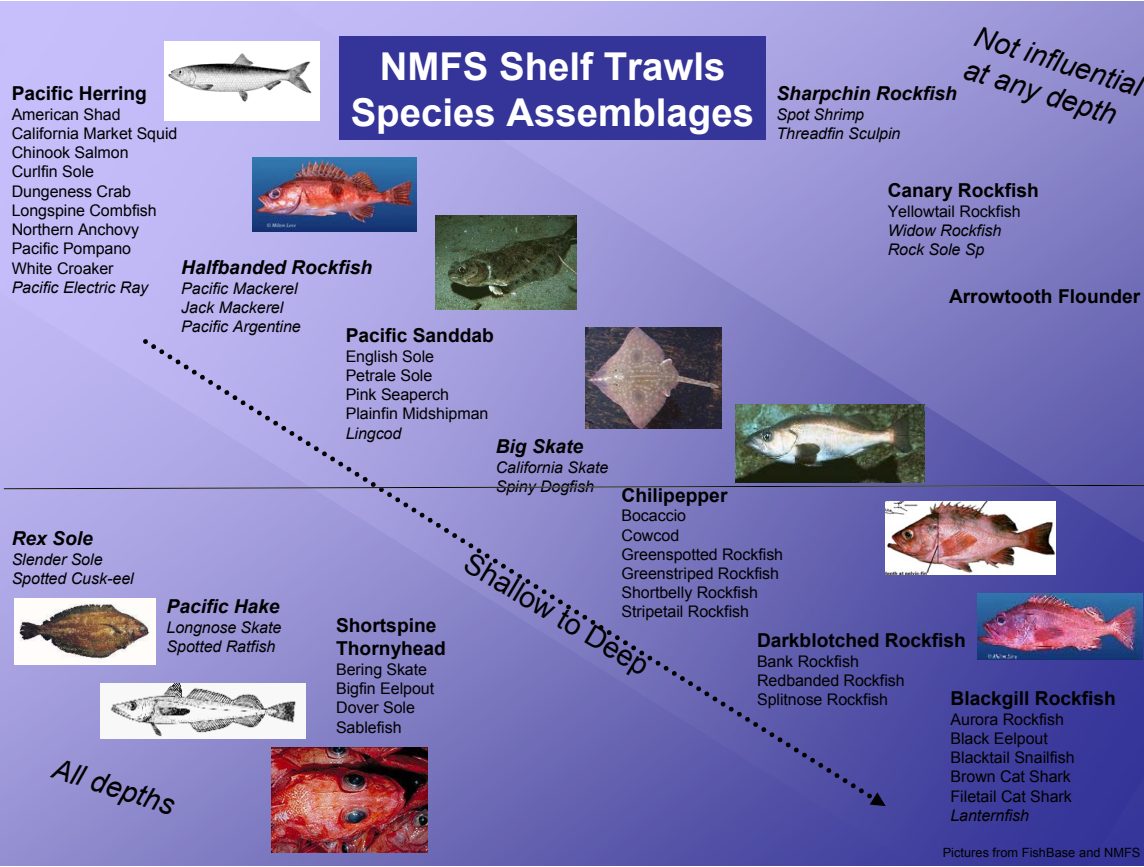


Figure 20. Species assemblage results for the shelf trawls. Assemblages are named for the most influential species in each group. Assemblages are arranged from shallow to deep, unless they are influential at all or none of the depths. The assemblages that were not influential at any depth were composed of relatively rare species, making depth associations indiscernible given the methodology for defining “influential” assemblages. Non-italicized species were consistently placed into the same species assemblage >80% of the time; italicized species tended to roam into other assemblages with random sampling.

- Determine which species tended to be caught together (species assemblages);
- Analyze fishing locations to determine which locations contained similar catches (site groups);
- Resolve where the species assemblages were being caught by combining results from objectives A and B and then utilizing GIS to map the results; and
- Identify significant relationships between site groups identified in objective B and broad scale habitat characteristics (bathymetry, bathymetric complexity, and large-scale habitat classification).

Clustering is a technique used to summarize information into similar groups. The 1-Pearson correlation coefficients with the average means clustering method (see "Introduction to Clustering" pp. 14) was used to first summarize fish species into assemblages, and to then summarize catch locations into site groupings. In order to determine how variable the species cluster results could be within the data, a modified bootstrapping procedure was employed on 50 random samples composed of 50% of the data and the results compared for persistence and precision. Additionally, the data from 1989 to 2001 were analyzed separately to determine if current conditions have changed enough to affect the resultant species assemblages. Conditions that could have changed through time include: abiotic shifts, such as decadal shift in water temperature; biotic shifts, such as depletion of key species; or effort shifts, such as fishing farther offshore. The location of the eight site groups

were mapped using GIS. To determine which species groups were influential in forming the site groups, the average frequency of occurrence for species assemblages in each site group was calculated. Species assemblages were considered influential if, on average, species were present in 25% of the trawls in a site group. Two-way analyses of variance (ANOVA) were conducted with depth (pp. 37) and latitude, sediment (pp. 38), and bathymetric complexity (pp. 16) to determine if any of these factors have an influence on the site group results at the scale of this analysis.

RESULTS AND DISCUSSION

Species Assemblages (Objective A)

Thirteen species assemblages were determined in the NMFS trawl data set and named according to the most influential species (Figure 20). There were no differences in the results when data from 1989-2001 were analyzed separately. Overall, the species assemblages delineated were robust; eight of the thirteen groups were consistently placed together for more than 80% of the random samples. This provides confidence that the results do not represent just random groupings. Running the modified bootstrap technique can provide an estimate of the precision of results, but verifying the accuracy of the results is more difficult. Comparisons of the results with past studies can give feedback on the accuracy. Assemblages are not static and may modify in response to environmental parameters, such as warm or cold conditions (see CD-ROM for changes in species assemblages in response to water temperature).

The species cluster results from the shelf trawls make intuitive sense in many ways. For example, most of the pelagic species were clustered together (Pacific herring assemblage), and the soft bottom and hard bottom species are separated for most of the groups. Only a few assemblages contain both soft bottom and hard bottom species, for example the inclusion of the soft bottom-associated stripetail rockfish and rock sole with hard bottom assemblages (bocaccio and canary rockfish, respectively), and the placement of stripetail rockfish (hard bottom) in the darkblotched rockfish assemblage (soft bottom) (Love et al., 2002). The chilipepper group contains fish species that are benthic as well as midwater schoolers, suggesting that even though these species behave differently they are responding to similar habitat characteristics.

Site Group (Names based on depth)	N	Depth±SD (meters)
Group 78 meters	125	78 ± 16 ^a
Group 93 meters	103	93 ± 19 ^b
Group 96 meters	136	96 ± 25 ^b
Group 119 meters	72	119 ± 37 ^c
Group 153 meters	171	153 ± 41 ^d
Group 268 meters	116	268 ± 52 ^e
Group 328 meters	37	328 ± 51 ^f
Group 415 meters	123	415 ± 48 ^g

Table 3. Site group results for shelf trawl data. The numbers of trawls associated with each group as well as average depth ± standard deviation are provided. Different letters signify a significant difference using Tukey’s pairwise comparison on log adjusted depth with overall alpha set at 0.001.

Subsection 2.1.1: ASSEMBLAGE ANALYSES

tics. Love et al. (2002) mention species co-occurrences, such as the association of cowcod (immature) with bocaccio and greenstripe rockfish, which are corroborated by the results of this analysis. However, this study, unlike Love, found that striptail rockfish and a splitnose rockfish did not occur together. The placement of yellowtail rockfish, canary rockfish, and widow rockfish together in this analysis is supported by multiple studies (Tagart and Wallace, Leet, 2001, Star et al., 2002).

All rockfish groups concurred with the broad characterization by NMFS (into near-shore, shelf, and slope species groups), which were based on an assemblage analysis completed by Gabriel and Tyler (1980). Williams and Ralston (2002) used the same data set as this study to examine rockfish species assemblages. Their “southern shelf group” contained species clustered together in this report’s chilipepper and canary groups, while their “deep-water slope” group was split among three groups in this report. The results from submersibles (Yoklavich et al., 2000, 2002; Hixon et al., 1991; Hixon and Tissot, 1992; Field et al., 2002) provide relevant species/habitat interactions at a scale meaningful to fish, however, many of the results from these studies are not comparable with the current studies due to the large difference in scale. Hixon et al. (1991) documented that the species composition observed from the submersibles was different than species captured in trawls.

Site Groups and Interaction of Species and Sites (Objectives B and C)

Eight site groups were identified from the 883 shelf trawls (Table 3). To make interpretation easier, the site groups are named according to mean depth. All but two groups are significantly different in depth using an ANOVA (Table 3). The importance of depth in this ecosystem is not a new idea; many researchers have already com-

	Group 78 meters	Group 93 meters	Group 96 meters	Group 119 meters	Group 153 meters	Group 268 meters	Group 328 meters	Group 415 meters
Rex Sole Assemblage	0.64	0.59	0.82	0.74	0.80	0.78	0.93	0.63
Pacific Hake Assemblage	0.41	0.37	0.62	0.39	0.58	0.61	0.87	0.68
Shortspine Thornyhead Assemblage	0.20	0.23	0.28	0.32	0.39	0.64	0.96	0.83
Pacific Herring Assemblage	0.63	0.31	0.34	0.21	0.06	0.01	0.01	0.01
Halfbanded Assemblage	0.22	0.27	0.11	0.24	0.07	0.02	0.01	0.01
Pacific Sanddab Assemblage	0.90	0.91	0.88	0.82	0.55	0.13	0.10	0.03
Big Skate Assemblage	0.27	0.26	0.40	0.25	0.25	0.16	0.24	0.12
Chilipepper Assemblage	0.12	0.26	0.22	0.57	0.61	0.42	0.12	0.03
Darkblotched Assemblage	0.01	0.00	0.03	0.03	0.10	0.41	0.41	0.17
Blackgill Rockfish Assemblage	0.01	0.01	0.00	0.02	0.01	0.05	0.30	0.56
Canary Assemblage	0.02	0.10	0.06	0.21	0.15	0.04	0.01	0.00
Sharpchin Assemblage	0.01	0.01	0.02	0.05	0.13	0.23	0.10	0.01
Arrowtooth Flounder Assemblage	0.00	0.05	0.01	0.01	0.11	0.14	0.14	0.02

Table 4. Average frequency of occurrence of fish species assemblages (percent occurrence calculated for each species and then averaged for each fish assemblage) for each shelf site group. Numbers in bold represent influential species assemblages within that site group.

mented on its influence (Williams and Ralston, 2002; Sullivan, 1995; Gabriel and Tyler, 1980; Field et al., 2002; Matthews and Richards, 1991). Species assemblages which were influential in forming each site group are identified (Table 4). The interaction between site groups and species assemblages (i.e. the location of species assemblages) reemphasized the relationship between species and depth. Three species groups (rex sole, Pacific hake, and shortspine thornyhead assemblages) had a high frequency of occurrence in all trawl groups. The rest of the species groups were arranged from shallow to deep. In all cases, the assemblages with a low frequency of occurrence for all site groups were composed of relatively rare species. Depth associations were present, just not discernible given the methodology for defining “influential” assemblages. The location of the trawls designated to each site group were mapped using GIS (Figure 21).

Habitat Correlations (Objective D)

Other factors besides depth can have an impact on species assemblages. Examples of these factors include latitude (Horn and Allen, 1978; Sullivan, 1995), sediment type (Yoklavich et al., 2000, 2002; Field et al., 2002; Hixon et al., 1991; Hixon and Tissot, 1992), and bathymetric relief (see bathymetric complexity pp. 16) (Yoklavich et al., 2000, 2002; Field et al., 2002). Unfortunately, since there were significant interactions present between all of these variables and depth, it could not be determined if the significance detected for these factors was due to this interaction with depth. Even though bathymetric complexity increases as depth increases, group 268 has a higher bathymetric complexity than the groups around them with similar depth. It is interesting to note that for this data set, 89% of the trawls occurred over areas delineated as mud, and 8% over areas delineated as sand (pp. 38) making it impossible to examine the effects of sediment. However, all 15 trawls that occurred over habitat designated as “mud-rock mix” were clustered together into the “415 meters group”. All attempts to remove depth and determine secondary influences on group designation were unsuccessful. The non-linear relationship between the fish species and depth made removal of depth impossible. While these other factors appear to have a decreased significance when compared to depth, more complex analyses exploring ways to remove the effects of depth and determine the relative significance of these factors may be completed in Phase II.

In conclusion, this analysis provides results showing species assemblages, site assemblages, and the location of species assemblages for the important shelf environment. The species assemblages are relevant to the scale of a commercial trawl. The larger species assemblages that were reported in the literature were confirmed (NMFS near-shore, shelf and slope groups). For the most part, pelagic, soft bottom, and hard bottom species assemblages were distinguished, providing initial feedback to the accuracy of the species assemblages.

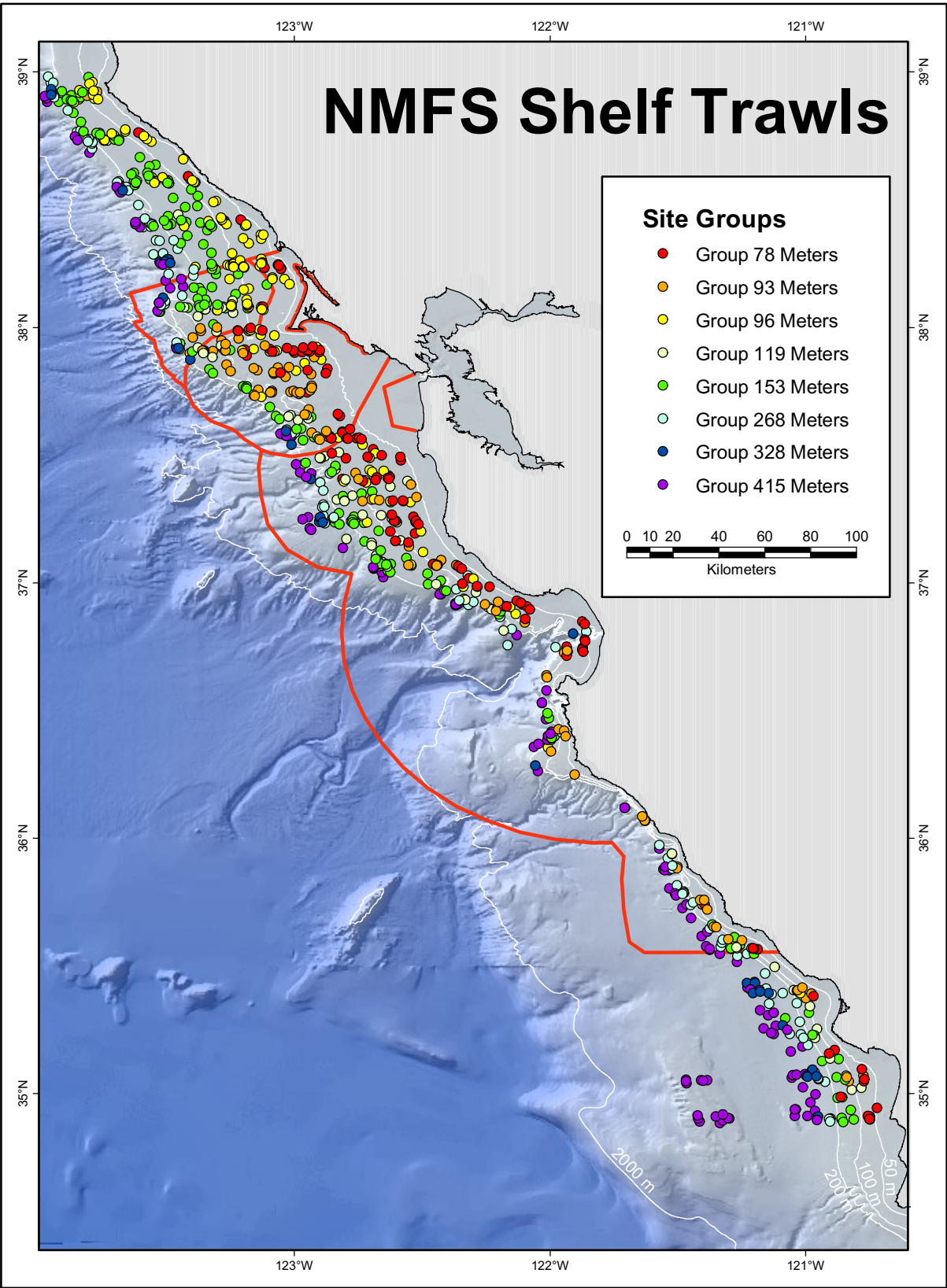


Figure 21. Location of site groups for NMFS shelf trawls. Lines showing the 50, 100, 200, and 2,000 depth contours are provided.

Subsection 2.1.1: ASSEMBLAGE ANALYSES

ABOUT THIS MAP

Little is known about the deep slope species, especially information on which species are found together on what habitats. Multivariate statistics were used to analyze species assemblages over trawlable habitats between 190 and 1280 meters depth off California. This is the first attempt to exclusively define species assemblages on the deep slope community. For an introduction to the continental slope ecosystem, see the *Ecological Linkages Report*. Eight species assemblages (Figure 22) and seven site groups (Table 5, Figure 23) were identified. The average frequency of occurrence of species assemblages (percent occurrence calculated for each species and then averaged for each fish assemblage) within each site group was calculated to analyze the interaction between the species assemblages and site groups (Table 6). As with all data sets, the most significant result was the effect of depth on species assemblages. All attempts to isolate and remove the effects of depth in order to determine secondary effects were unsuccessful. Certainly secondary effects exist, but at the scale of this study, they were not discernible. Our results support previous results by Williams and Ralston (2002), Sullivan (1995), Field et al. (2002), Gabriel and Tyler (1980), and Matthews and Richards (1991), who found bathymetry to be an important factor in defining demersal fish assemblages on the West Coast. Through this analysis a large amount of information has been condensed down to assemblages of co-occurring species, as well as groups of similar locations. A map is provided to visually portray the spatial arrangement of the results.

DATA SOURCES

Data from 454 fisheries independent research trawls between depths of 190-1280 meters were collected in 1991, 1997, 1999, 2000, and 2001, during the months of July-November. For 1999, 2000, and 2001 (NWFSC), gear included an aberdeen net with a small mesh liner (2 inches stretched) at the codend which was trawled along the bottom along east-west transects for 15 minutes. For 1991, 1997, 1999, and 2000 (AKFSC), gear included a nor'easter (127 mm stretched-mesh body, 89 mm stretched-mesh codend, and 32 mm stretched-mesh codend liner) with a rubber bobbin roller which was trawled on the bottom for 15-30 minutes. Although different gears were utilized in this data set, preliminary analyses found no significant difference between years, allowing the data sets to be combined (pers com Tonya Builder, NMFS). Data was adjusted for effort and statistical assumptions as in the NMFS Shelf Trawls. The data set contained information on 161 fish species, but after removal of rare species, the matrix used for classification contained 52 fish and 10 invertebrate species. A list of common and scientific names of species included in this analysis is available on the accompanying CD-ROM. Since each NMFS cruise hosted scientists with varying levels of expertise in invertebrate identification, NMFS scientists recommended that only well known/common invertebrate species be included in the analyses. Fish species assemblages were identical with and without the inclusion of invertebrates in the analysis. For more information on how the data were collected, including site selection procedures for each data set, see Turk et al. (2001) and Lauth (2001).

METHODS

The aim of the entire assemblage analysis was to increase our understanding of the biogeography of fishes and macro-invertebrates in relationship to their environment, and identify important areas or habitats. Four of the five main

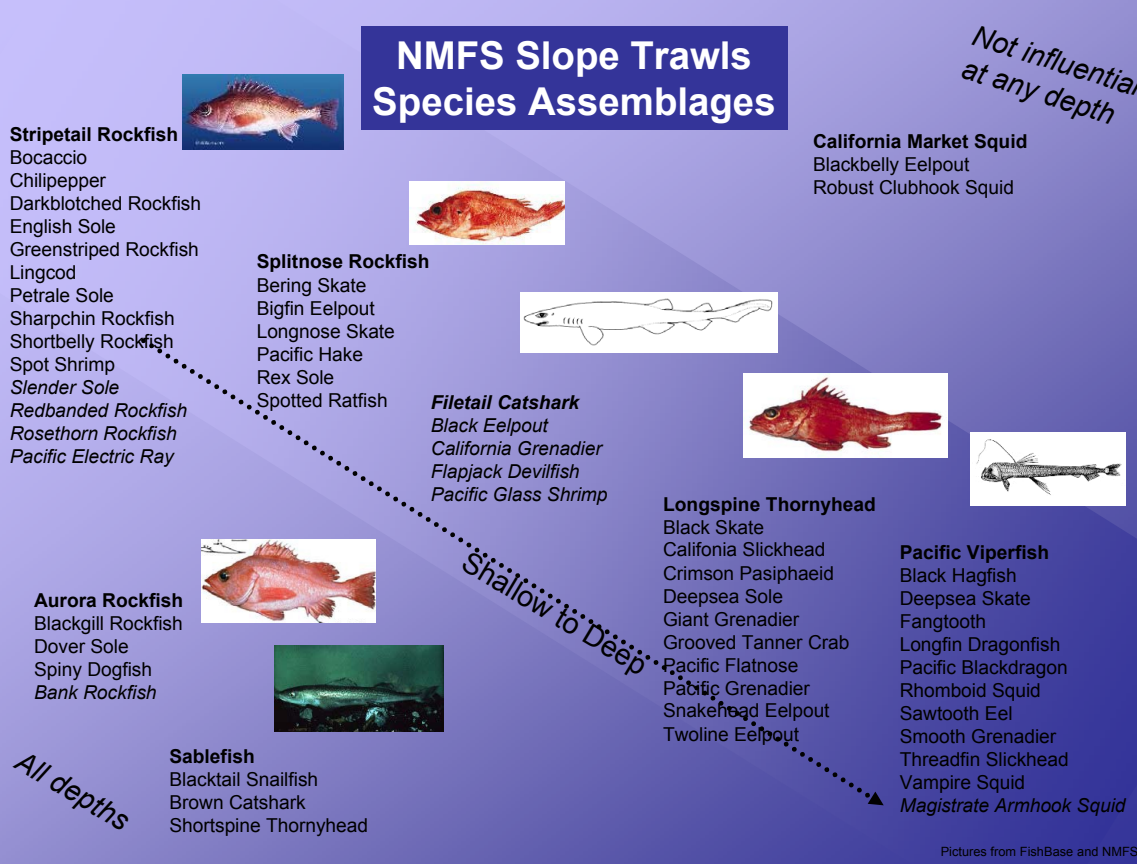


Figure 22. Species assemblage results for the slope trawls. Assemblages are named for the most influential species in each group. Assemblages are arranged from shallow to deep, unless they are influential at all or none of the depths. The assemblages that were not influential at any depth were composed of relatively rare species, making depth associations indiscernible given the methodology for defining “influential” assemblages. Non-italicized species were consistently placed into the same species assemblage >80% of the time; italicized species tended to roam into other assemblages with random sampling.

objectives were addressed in this analysis:

- Determine which species tended to be caught together (species assemblages);
- Analyze fishing locations to determine which locations contained similar catches (site groups);
- Resolve where the species assemblages were being caught by combining results from objectives A and B and then utilizing GIS to map the results; and
- Identify significant relationships between site groups identified in objective B and broad scale habitat characteristics (bathymetry, bathymetric complexity, and large-scale habitat classification).

Clustering is a technique used to summarize information into similar groups. The 1-Pearson correlation coefficients with the average means clustering method (see introduction to clustering pp. 14) was used to first summarize the fish species into assemblages, and to then summarize the catch locations into site groupings. In order to determine how variable the species cluster results could be within the data, a modified bootstrapping procedure was employed on random samples composed of 50% of the data and the results compared for persistence and precision. The location of the seven site groups were mapped using GIS. To determine which species groups were influential in forming the site groups, the average frequency of occur-

rence for species assemblages in each site group was calculated. Species assemblages were considered influential if, on average, species were present in 25% of the trawls in a site group. Two-way analyses of variance (ANOVA) were conducted with depth and latitude, sediment, and bathymetric complexity, to determine if any of these factors have an influence on the site group results at the scale of this analysis.

RESULTS AND DISCUSSION

Species Assemblages (Objective A)

Eight species assemblages were determined for the NMFS slope trawls, and named according to the most influential species (Figure 22). Overall, the species assemblages delineated were robust; seven of eight assemblages were consistently placed together for more than 80% of the random samples. This provides confidence that the results do not represent just random groupings. Running the modified bootstrap technique can provide an estimate of the precision of results, but verifying the accuracy of the results is more difficult.

The species cluster results from these NMFS slope trawls seem much less intuitive than those from the NMFS shelf trawls. This is partly due to a lack of research and subsequent decreased understanding of the behavior of slope species. Many of the species from the NMFS slope trawls understandably overlap with species from the NMFS shelf trawls. Surprisingly, some of the species interactions noted with the shelf trawls are not upheld with the slope data. The stripetail rockfish slope assemblage is composed of all of the shallower species (soft and hard bottom) that were distributed among 6 shelf assemblages. This does not imply that species co-occurrences changed between the shelf and slope trawls, just that cluster results were sensitive to the depth range covered by the data set.

Love et al. (2002) provides a summary of rockfish habitat requirements and species co-occurrences. However, since only 15 (24%) species are rockfish, this information cannot be used to assess all results. None of the assemblages in this study completely agree with species co-occurrences listed in Love et al. (2002). For example, Love et al. stated that stripetail rockfish and splitnose rockfish are found together. However, within both the shelf and slope data sets of this analysis the stripetail and splitnose rockfish were placed into different groups. The results are consistent with the large scale assemblages design-

Site Group (Names based on depth)	N	Depth±SD (meters)
Group 263 meters	84	263 ± 49 ^a
Group 410 meters	86	410 ± 46 ^b
Group 530 meters	43	530 ± 42 ^c
Group 622 meters	29	622 ± 27 ^d
Group 733 meters	48	733 ± 71 ^e
Group 931 meters	90	931 ± 132 ^f
Group 1112 meters	74	1112 ± 95 ^g

Table 5. Site group results for slope trawl data. The numbers of trawls associated with each group as well as average depth ± standard deviation are provided. Different letters signify a significant difference using Tukey’s pairwise comparison on log adjusted depth with overall alpha set at 0.001.

Subsection 2.1.1: ASSEMBLAGE ANALYSES

nated by NMFS: near-shore, shelf, and slope species groups (NMFS, 2002). All of the rockfish in each species assemblage from this study come from the same NMFS group. The rockfish groups identified by Williams and Ralston (2002) were not completely corroborated by this study. The species in their “southern shelf group” were placed into the stripetail rockfish group which included all shallow-water species. However, their “deep water slope” group was split among four of this report’s groups. Comparisons of the results from this study with other assemblage studies are difficult due to the variability in species analyzed between studies, the different habitats targeted, and the discrepancy in scale. For example, results from submersibles (Yoklavich et al., 2000, 2002; Hixon et al., 1991; Hixon and Tissot, 1992; Field et al., 2002) record interactions at a much smaller scale compared to trawls, which can fish multiple habitats during a 1 km tow.

Site Groups and Interaction of Species and Sites (Objectives B and C)

Seven site clusters were identified from the 454 slope trawls (Table 5). To make interpretation easier, the site groups are named according to mean depth. Species assemblages which were influential in forming each site group are identified. The average frequency of occurrence of fish species assemblages for each site group (Table 6) was used to determine where species assemblages were found. An ANOVA determined that all groups were significantly different in depth (Table 5). The importance of depth in this ecosystem is not a new idea; many researchers have already commented on its influence (Williams and Ralston, 2002; Sullivan, 1995; Gabriel and Tyler, 1980; Field et al., 2002; Matthews and Richards, 1991). Latitude has also been described as having an influence on California fish species composition (Williams and Ralston, 2002; Horn and Allen,

1978; Sullivan, 1995), but for the area of this study, no latitudinal results were evident.

The interaction between site groups and species assemblages (i.e. the location of species assemblages), reemphasized the relationship between species and depth (Table 6). The species groups were arranged such that they went from shallow to deep. In all cases, the assemblages with a low frequency of occurrence for all site groups were composed of relatively rare species. Depth associations were present, just not discernible, given the methodology for defining “influential” assemblages. The location of the trawls contained in each site group were mapped (Figure 23).

Habitat Correlations (Objective D)

Other factors besides depth, such as latitude (Williams and Ralston, 2002; Horn and Allen, 1978; Sullivan, 1995), bottom composition (Yoklavich et al., 2000, 2002; Field et al., 2002; Hixon et al., 1991; Hixon and Tissot, 1992), or bathymetric complexity (pp. 16) (Yoklavich et al., 2000, 2002; Field et al., 2002) can have an impact on species assemblages. For this data set, 95% of the trawls occurred over areas delineated as mud (pp. 38), making it impossible to examine the effects of bottom composition. It is interesting to note that of all the 16 trawls completed over the bottom type designated as a combination of mud and rock, 33 percent occurred in the “410 meters” site group, and 56 percent in the “deepest” group. For the slope trawls, there was no interaction present between depth and bathymetric complexity or latitude, so the effects of these parameters could be tested. Neither bathymetric complexity (pp 16), nor latitude, had a significant impact on site grouping when the effect for depth was accounted for (bathymetric complexity: $df=1$, $F=0.94$, $P=0.33$; latitude: $df=1$, $F=0.11$, $P=0.74$).

	Group 263 meters	Group 410 meters	Group 530 meters	Group 622 meters	Group 733 meters	Group 931 meters	Group 1112 meters
Sablefish Assemblage	0.41	0.78	0.87	0.97	0.95	0.84	0.68
Aurora Rockfish Assemblage	0.40	0.75	0.55	0.31	0.27	0.25	0.17
Stripetail Rockfish Assemblage	0.51	0.08	0.00	0.00	0.00	0.00	0.00
Splitnose Rockfish Assemblage	0.88	0.92	0.64	0.36	0.18	0.04	0.06
Filetail Catshark Assemblage	0.03	0.33	0.51	0.43	0.23	0.08	0.05
Longspine Thornyhead Assemblage	0.01	0.05	0.22	0.41	0.65	0.87	0.84
Pacific Viperfish Assemblage	0.01	0.02	0.06	0.09	0.14	0.16	0.27
Market Squid Assemblage	0.14	0.15	0.13	0.07	0.07	0.03	0.05

Table 6. Average frequency of occurrence of fish species assemblages (percent occurrence calculated for each species and then averaged for each fish assemblage) for each slope site group. Bold numbers represent influential species assemblages within that site group.

In conclusion, this analysis provides results showing species assemblages, site assemblages, and the location of species assemblages for the deep slope environment that are relevant to the scale of a commercial trawl. The larger species assemblages that were reported in the literature were confirmed (NMFS, 2002) (near-shore, shelf and slope groups), but some of the smaller groups were not corroborated. Half of the sites designated as “1,112 meters” are located outside sanctuary boundaries. This is mainly due to the large number of deep sites located to the south and west of Sanctuary boundaries. The results of this analysis in conjunction with similar analyses on the three other data sets provides a fairly comprehensive overview of fish and macro-invertebrate species within the study area.

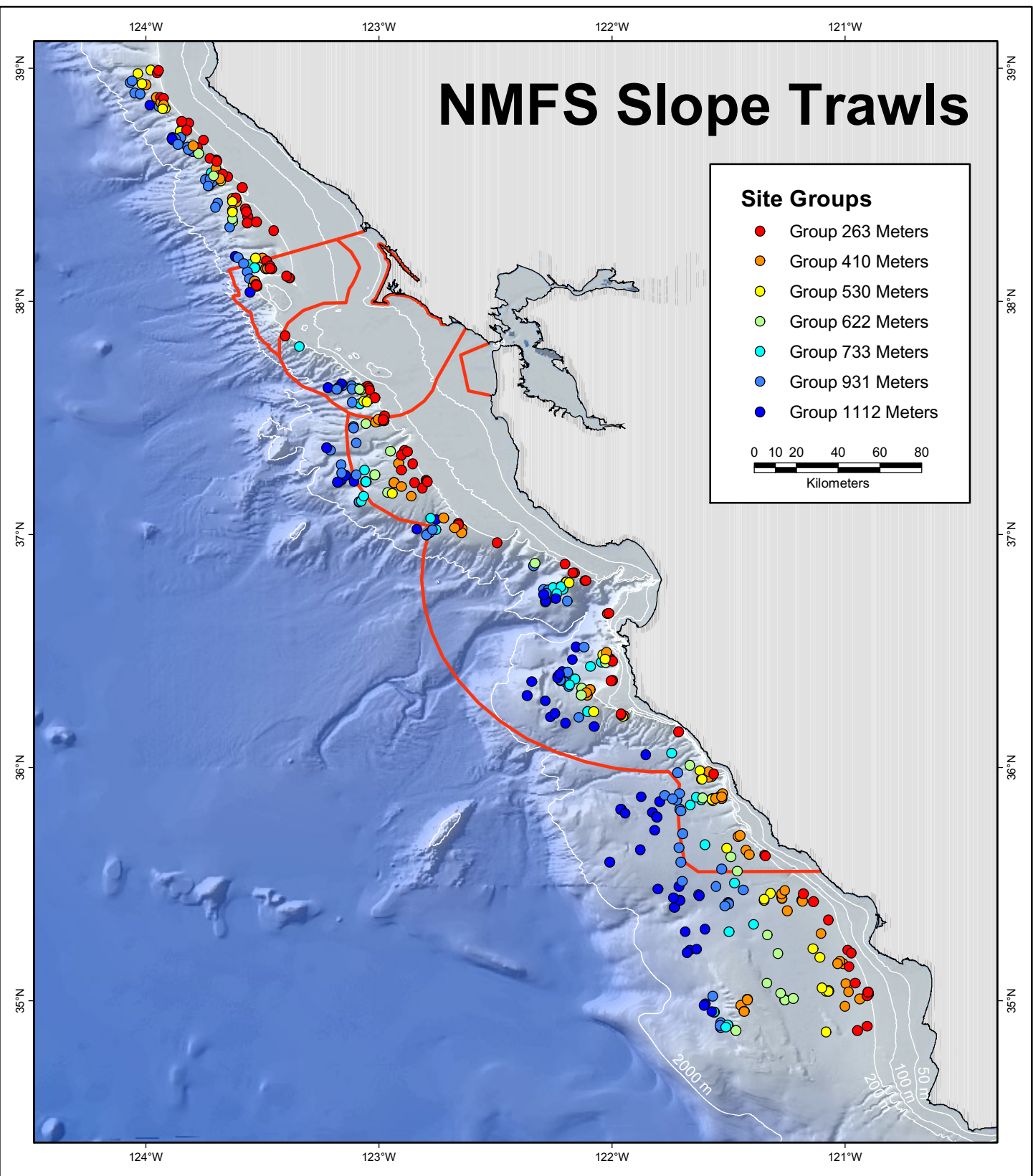


Figure 23. Location of site groups for NMFS slope trawls. Lines showing the 50, 100, 200, and 2,000 depth contours are provided.

Subsection 2.1.1: ASSEMBLAGE ANALYSES

ABOUT THESE MAPS

The pelagic environment is home to many marine species at some stage in their life. Therefore, it is important to document what species interact in this environment, and determine environmental influences on species abundance. Multivariate statistics were used to analyze fish and invertebrate species assemblages caught in trawls conducted at 7 and 30 meters depth between Cordell Bank NMS and Monterey Bay. For more information on the neritic environment see the *Ecological Linkages Report*. When determining species assemblages, three separate analyses were completed: all data (1986-2001), only 1998 (warm year), and only 1999 (cold year). There were differences between years in the species present, as well as in the organization of species assemblages. The site groups identified were significantly related to environmental conditions, but the influential conditions varied between years. To investigate assemblages persistent over more than one year, all of the data collected was analyzed for species assemblages, but not for site assemblages, due to the difficulty in mapping assemblages through time as the same location may house any number of assemblages depending on environmental conditions. See Larson et al (1994) for a detailed analysis of rockfish assemblages in response to short-term environmental variability. Through this analysis a large amount of information has been condensed down to assemblages of co-occurring species, as well as groups of similar locations. Maps are provided to portray the spatial arrangement of the site groups for 1998 and 1999.

DATA SOURCES

Data from 1543 fisheries independent research trawls were collected from 1986-2001, during May and June. The purpose of the trawl was to determine the number and quantity of juvenile rockfish present during the upwelling season at night. The midwater trawl net was a “Cobb trawl” constructed of nylon webbing. A fine mesh (1.25 cm) liner was inserted in the codend to retain small midwater organisms. To open the net vertically, 42 8-inch floats were attached to the headrope and 145 pounds of chain was lashed to the footrope. To spread the net horizontally, 850 lb steel ‘V’ doors 5 x 7 feet in size were used. The net was deployed while the ship was underway at a speed of approximately 2.7 knots. Seventy-five meters of trawl cable were payed-out which nominally puts the headrope at a depth of 30 meters (100 feet), the depth at which most species of juvenile rockfishes are most abundant (Lenarz et. al., 1991). The spatial effort was consistent between years with 1-4 hauls completed at 32 stations (see Figure 26 for spatial extent of data). Analyses were completed for the entire data set, as well as 1998 and 1999 individually (representing warm and cold water years, respectively). Fish numbers were adjusted for effort by NMFS then log transformed for analyses. The data matrices used for classification contained data for 16, 24, and 41 species in 1998, 1999, and all years, respectively. A complete list of common and scientific names of the species included in these analyses is available on the accompanying CD-ROM.

METHODS

The aim of the entire assemblage analysis was to increase our understanding of the biogeography of fishes and macro-invertebrates in relationship to their environment, and identify important areas or habitats. Four of the five main objectives were addressed in this analysis:



Figure 24. Species assemblage results for the midwater trawls utilizing all data from 1986 to 2001. Assemblages are named for the most influential species in each group. Non-italicized species were consistently placed into the same species assemblage >80% of the time; italicized species tended to roam into other assemblages with random sampling.

- Determine which species tended to be caught together (species as assemblages);
- Analyze fishing locations to determine which locations contained similar catches (site groups);
- Resolve where the species assemblages were being caught by combining results from objectives A and B and then utilizing GIS to map the results; and
- Identify significant relationships between site groups identified in objective B and broad scale habitat characteristics (bathymetry, bathymetric complexity, and large-scale habitat classification).

Clustering is a technique used to summarize information into similar groups. The 1-Pearson correlation coefficients with the average means clustering method (see "Introduction to Clustering" pp. 14) was used to first summarize the fish species into assemblages, and to then summarize the catch locations into site groupings. Species assemblages were determined for 1998, 1999, and all data, but site groups were only determined for 1998 and 1999. In order to determine how variable the species cluster results could be within the data, a modified bootstrapping procedure was employed on random samples composed of 75% of the data and the results compared for persistence and precision. The location of the site groups were mapped using GIS. To determine which species groups were influential in forming the site groups, the average frequency of occurrence for species assemblages in each site group was calculated. Species assemblages were considered influential

if, on average, species were present in 25% of the trawls in a site group. Interactions between environmental variables (salinity, temperature, density, bottom depth, and bathymetric complexity) were investigated by conducting step-wise discriminant analyses.

RESULTS AND DISCUSSION

Species Assemblages (Objective A)

The neritic environment is an important ecosystem in central California. Most benthic species have a larval stage dependent on the neritic environment. In addition, neritic species are an important base for the food web for fish, birds, and mammals. Due to the removed rare species, different species were included in the analyses depending on the year (1998, 1999, or all years). Ten species were present in 1999 that were absent in 1998, including six species of juvenile rockfish. For 1998 and 1999, there were five and six species assemblages identified, respectively, and seven species assemblages were differentiated in the entire data set. Species assemblages were named according to the most influential species (Figures 24, 25, 27). Overall, the species assemblages were much less robust than those from the other data sets. Average persistence (percentage of time species were grouped together) through random runs varied from 36% to 94% for all assemblages. This variability in results reflects two things: 1) the ephemeral nature of the neritic ecosystem and its expression through the species assemblages, and 2) the higher variability in results from the random runs due to smaller sample size. Some of the persistent groups (persistent through random runs as well as persistent through the three analyses) were: 1) market squid, northern anchovy, Pacific electric ray, and Pacific sardine; 2) euphasid, Pacific hake, and deep sea smelt; and 3) myctophid and slender barracuda. Different juvenile rockfish were present in 1998 and 1999. In 1998, a warm year, only shortbelly and stripetail rockfish were in greater than 5% of the trawls, and were grouped together. In 1999, a cold year, 8 species of juvenile rockfish were identified, and all grouped together except for blue rockfish and stripetail rockfish. This supports the observation by Loeb et al. (1994), Yoklavich et al. (1996), and Moser et al. (2000), that warm (El Niño) years are not good for rockfish recruitment. For the entire data set there were thirteen species of rockfish, which were all grouped together except for copper rockfish complex and brown rockfish. The consistent grouping of juvenile rockfish together suggests that the rockfish species are responding to similar environmental conditions. The copper and brown rockfishes are not well known; however, Larson et al. (1994) looking at the midwater trawls in 1987 and 1988, determined that some species in the copper complex arrive later in the season than most other rockfish species, which could affect their association with assemblages.

Running the modified bootstrap technique can provide an estimate of the precision of results, but verifying the accuracy of the results is more difficult. Only two studies were identified which have investigated species assemblages in the neritic environment (Larson et al., 1994; Calliet et al., 1979). Larson et al. (1994) analyzed this data set (1987-1988) for juvenile rockfish assemblages, looking at each sweep individually, and described the short term variation in assemblages and environmental conditions. Longer term trends were not analyzed. Since the species groups changed with each sweep, and most rockfish were grouped together for this study, comparing

Subsection 2.1.1: ASSEMBLAGE ANALYSES

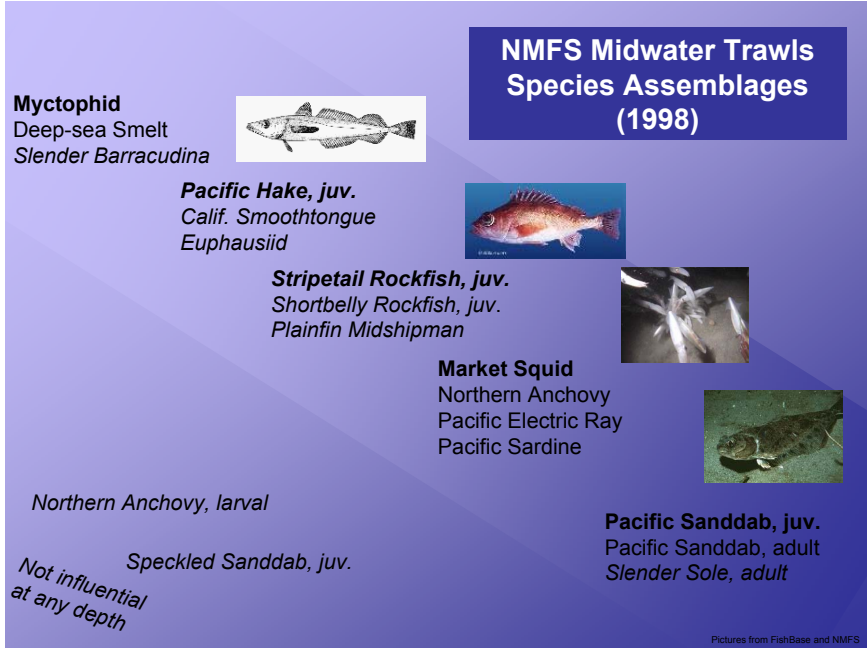


Figure 25. Species assemblage results for the midwater trawls conducted in 1998. Assemblages are named for the most influential species in each group. Non-italicized species were consistently placed into the same species assemblage >80% of the time; italicized species were more ephemeral and tended to roam into other assemblages with random sampling.

	Site group A	Site group B	Site group C	Site group D	Site group E	Site group F
N trawls	15	20	14	5	11	26
Myctophid Assemblage	0.00	0.02	0.02	0.00	0.18	0.49
Pacific Hake, juv. Assemblage	0.40	0.17	0.31	0.40	0.76	0.62
Stripetail Rockfish, juv. Assemblage	0.13	0.08	0.55	0.00	0.18	0.15
Market Squid Assemblage	0.33	0.58	0.29	0.00	0.30	0.07
Pacific Sanddab Assemblage	0.27	0.10	0.07	0.07	0.12	0.01

Table 7. Average frequency of occurrence of fish species assemblages (percent occurrence calculated for each species and then averaged for each fish assemblage) for each 1998 midwater site group. Number of trawls in each site group is provided in the first row. Bold numbers represent influential species assemblages within that site group.

results from the two studies is difficult. Calliet et al. (1979) analyzed midwater trawls, and purse seines, to determine species assemblages associated with market squid in shallow and deep environments. In the results from anchovy hauls, only three species showed high affinity with market squid in both shallow and deep hauls: northern anchovy, pacific electric ray, and Pacific herring. This study's results are similar since all species assemblages placed market squid, northern anchovy, and Pacific electric ray together. Pacific herring were not present in this analysis.

Site Groups and Interaction of Species and Sites (Objectives B and C)

For 1998 and 1999, six site groups were identified for each year. No analysis was run to group sites from the entire data set, since preliminary results suggested no spatial trends in results. Because groups are from midwater environments they are not named by depth, but distinguished as site group A, site group B, etc. Species assemblages which were influential in forming each site group are identified. The average frequency of occurrence of fish species assemblages for each site group (Tables 7 and 8) is used to determine where species assemblages were found. Maps with the location of the site groups are provided (Figures 26 and 28). Multiple assemblages can be found at the same site as 3-4 sweeps were made per year and environmental conditions could change between sweeps (see Larson et al, 1995).

Habitat Correlations (Objective D)

Depending on the data set, various environmental conditions had a significant influence on site groups. In 1998, a warm year, bottom depth (log transformed: N=91, F=18.94, P=<0.0001) was significant. In 1999, a colder year, bottom depth (log transformed: N=91, F=23.87, P=<0.0001), latitude (N=91, F=8.76, P=<0.0001), and water density (N=91, F=5.93, P<0.0001) were significant. The significance of bottom depth to each analysis highlights the importance of location on species assemblages even in the neritic environment. Groups were labeled according to their mean depth (i.e. the shallowest group was group A and the deepest was group F). The Pacific sanddab assemblage in 1998 and market squid assemblage in 1999 were only influential in the shallowest site group. In 1999 there was a north/south split where group F was more southern and groups B and C more northern (except for one point each south of Point Año Nuevo). In 1998, there were only two rockfish species captured in greater than 5% of the trawls (stripetail rockfish as-

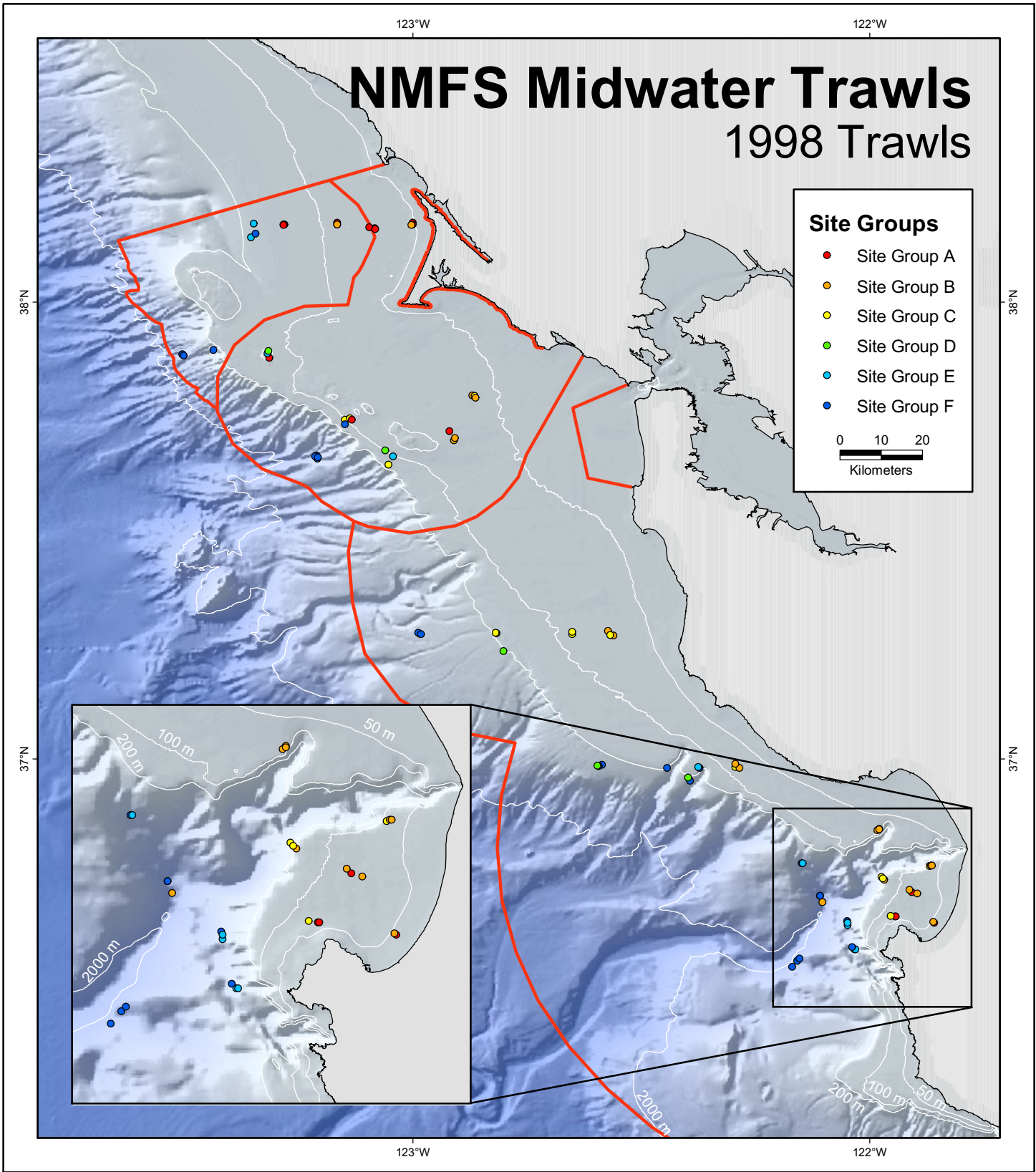


Figure 26. Location of site groups for NMFS 1998 midwater trawls. Lines showing the 50, 100, 200, and 2,000 depth contours are provided.

Subsection 2.1.1: ASSEMBLAGE ANALYSES



Figure 27. Species assemblage results for the midwater trawls conducted in 1999. Assemblages are named for the most influential species in each group. Non-italicized species were consistently placed into the same species assemblage >80% of the time; italicized species were more ephemeral and tended to roam into other assemblages with random sampling.

	Site group A	Site group B	Site group C	Site group D	Site group E	Site group F
N trawls	23	7	9	21	16	15
Pacific Hake, juv. Assemblage	0.21	0.37	0.40	0.33	0.69	0.77
Canary Rockfish, juv. Assemblage	0.08	0.02	0.25	0.07	0.53	0.15
Medusafish	0.04	0.00	0.11	0.05	0.13	0.00
Pacific Hake, adult	0.04	0.00	0.00	0.38	0.06	0.00
Pacific Saddab, juv. Assemblage	0.40	0.14	0.30	0.34	0.19	0.27
Market Squid Assemblage	0.55	0.11	0.06	0.12	0.05	0.03

Table 8. Average frequency of occurrence of fish species assemblages (percent occurrence calculated for each species and then averaged for each fish assemblage) for each 1999 midwater site group. Number of trawls in each site group is provided in the first row. Bold numbers represent influential species assemblages within that site group.

semblage) which were only influential in site group C. In 1999, there were six rockfish species grouped together (canary rockfish assemblage), which were influential for site groups C and E. The 1999 rockfish were caught in trawls further offshore than the trawls that contained rockfish in 1998.

These analyses provide trends in species assemblages in the midwater environment during the upwelling season. The grouping of juvenile rockfish together suggests that when conditions are suitable for one species, they are also suitable for the other species. Within the entire data set, three species assemblages were consistently grouped together greater than 80% of the time: Pacific hake, juv. assemblage; canary rockfish, juv. assemblage; and spiny dogfish assemblage. Two groups were slightly less stable and were grouped together greater than 70% of the time: medusafish assemblage and market squid assemblage. Even though results were not as stable as with the other data sets, this analysis identifies assemblages that were consistent through time. The reduced number of species present in 1998 highlights the effects of water temperature on species assemblages in the neritic environment. For this data set, both bottom depth, latitude, and water density were found to have a significant influence on site groups.

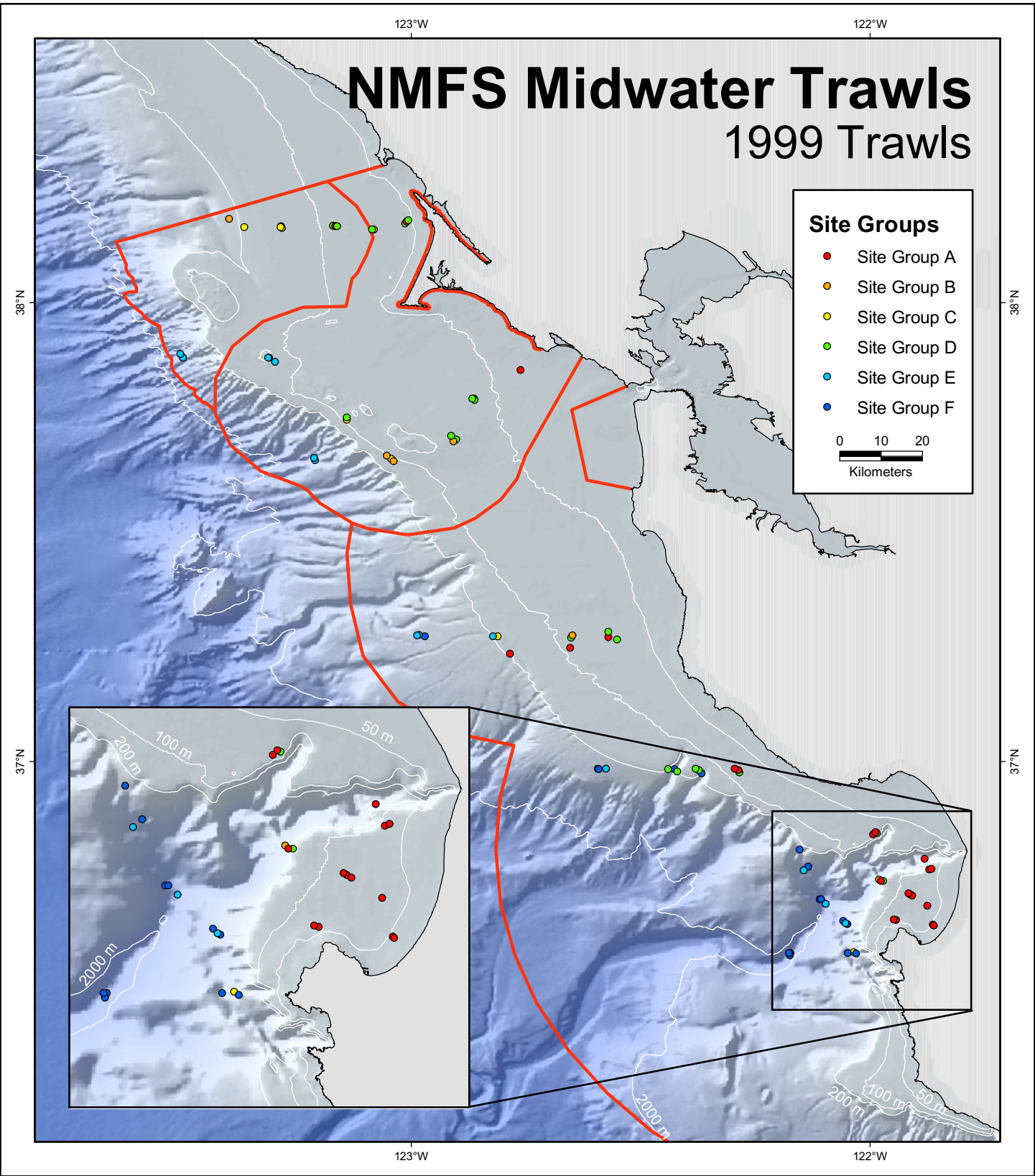


Figure 28. Location of site groups for NMFS 1999 midwater trawls. Lines showing the 50, 100, 200, and 2,000 depth contours are provided.

Subsection 2.1.1: ASSEMBLAGE ANALYSES

SECTION SUMMARY

Twenty-eight species assemblages were identified from the CDF&G recreational, NMFS shelf, and NMFS slope data sets. Figure 29 illustrates the overlap between the three data sets. The length of the vertical line depicts the depth interval where species assemblages were "influential" (see Tables 2, 4, 6-8). Shading was included to give the impression of where the continental shelf end and continental slope begins. The edge between the shelf and slope, although variable within the study area, was presented at 200 meters to be consistent with Williams and Ralston (2002). In all cases, the assemblages with a low frequency of occurrence at all depths were composed of species present in less than 20% of the trawls. For these assemblages, depth associations may have been present, just not discernible, given the methodology for defining "influential" assemblages.

Data Sources

See associated sections for information and spatial extent of CDF&G recreational hook and line data (pp. 23), NMFS demersal trawls on the continental shelf (pp. 26), and NMFS demersal trawls on the continental slope (pp. 28).

Methods

Results from the overlap between species assemblages and site groups from each analysis (see Tables 2, 4, 6-8) were used to determine the depths at which species assemblages were present. For each assemblage, the shallowest site group (mean depth minus the standard deviation) from which their average frequency of occurrence was >25% was used to determine the minimum depth. Similarly, the mean plus the standard deviation for the deepest site group was used to determine the maximum depth.

Results and Discussion

The shallow assemblages had more limited depth ranges, which is not obvious given the log scale of depth in Figure 29. Species included with the three data sets differed, especially since only species caught in at least 5% of the trawls were analyzed. Therefore, while the NMFS shelf and slope trawls

may have overlapped for the 200-500 meters depth range, the species included in the analyses differed. It is interesting to note that the shallow water species included in the NMFS slope trawl analysis were all placed in one assemblage, the stripetail rockfish assemblage, and that this assemblage was only present in the shallowest slope trawl site group. The same species included in this stripetail rockfish assemblage were found in five different NMFS shelf assemblages. Conversely, the blackgill assemblage on the NMFS shelf trawls contains the deeper species caught in the shelf trawls and found within three different NMFS slope species assemblages. This does not imply that species co-occurrences changed between the shelf and slope trawls, just that cluster results were sensitive to the depth range covered by the data set. For example, bocaccio and English sole do not co-occur, as bocaccio is attracted to rocky ledges and English sole to soft bottom areas with low relief (Love et al., 2002). These species are grouped together 92% of the time when included in an analysis with deep slope species, but never grouped together when included in an analysis with shelf species.

The overlap between the shelf and recreational trawls was

more difficult to compare due to the different fishing methods employed. Only nine species overlap between the recreational data and the shelf trawls. For both data sets, chilipepper, green-striped rockfish, and greenspotted rockfish were grouped together (chilipepper and greenspotted assemblages) and found at similar depths. For the most part, fish species were associated with a shallower depth with the recreational hook and line analysis than with the shelf trawl analysis. This difference could be due to the nature of the assemblage analysis or due to the variable size selectivity of the fishing methods and habitats. Many of the deepwater rockfish species settle as juveniles in shallow water, and slowly shift to deeper water as they mature (Love et al., 2002). Future analyses could include information on fish total length to determine if ontogenetic shifts occur and if they generate the differences in species' depth range between data sets noted above. The effect water temperature has on the species present, and the composition of species assemblages, was investigated for the recreational and shelf data sets and provides preliminary results on which assemblages are persistent through environmental change (see CD-ROM).

For the midwater trawl data set, the importance of environmen-

tal conditions, especially seasonal water temperature (1998 warm year vs. 1999 cold year) was obvious in its influence on what species were present in the neritic environment during upwelling season. Using data from all years, species assemblages could be delineated, but these assemblages were more sensitive with regards to random samples. This emphasizes the ephemeral nature of the neritic environment, and the resulting transient nature of the species assemblages. There were three species assemblages that occurred together in all data sets: 1) Market squid, Northern anchovy, Pacific electric ray, and Pacific sardine; 2) Euphausiids, Pacific hake, and deep sea smelt; and 3) Myctophid and slender barracuda. In addition, most larval rockfish species co-occur. More in-depth analyses, taking advantage of the available information on environmental conditions, could be conducted (see Larson et al., 1994).

In conclusion, species assemblages and site groups were delineated and mapped for four separate data sets. Depth had a significant influence on all four data sets. The influence of depth is not a new concept (Williams and Ralston, 2002; Sullivan, 1995; Gabriel and Tyler, 1980; Field et al., 2002; Matthews and Richards, 1991); however, this is the first time a study has demonstrated its significance on three separate data sets. All attempts to remove depth and look for secondary influences on group designation were unsuccessful. For the neritic environment, depth, latitude, and water density had a significant impact on site groups in 1999. Starr (1998) addressed the implementation of rockfish no-take areas and made two important recommendations. First, in order to properly manage marine ecosystems, there is a need for a better understanding of fish assemblages. Once these assemblages are delineated, managers can take steps to ensure each assemblage receives proper management. The results from this study provide information on these assemblages for near-shore, shelf, slope, and midwater ecosystems. The second recommendation by Starr (1998) was to delineate rectangular no-take areas that cover 20-50 km of the coast and extend west to the edge of the continental shelf. From a biogeographic viewpoint, the spatial analyses coincide with that recommendation and also determined that deep slope communities contribute significantly to ground fish biogeographic patterns. Because assemblages follow bathymetry at the scale of this analysis, this approach could protect all demersal species assemblages identified in this study.

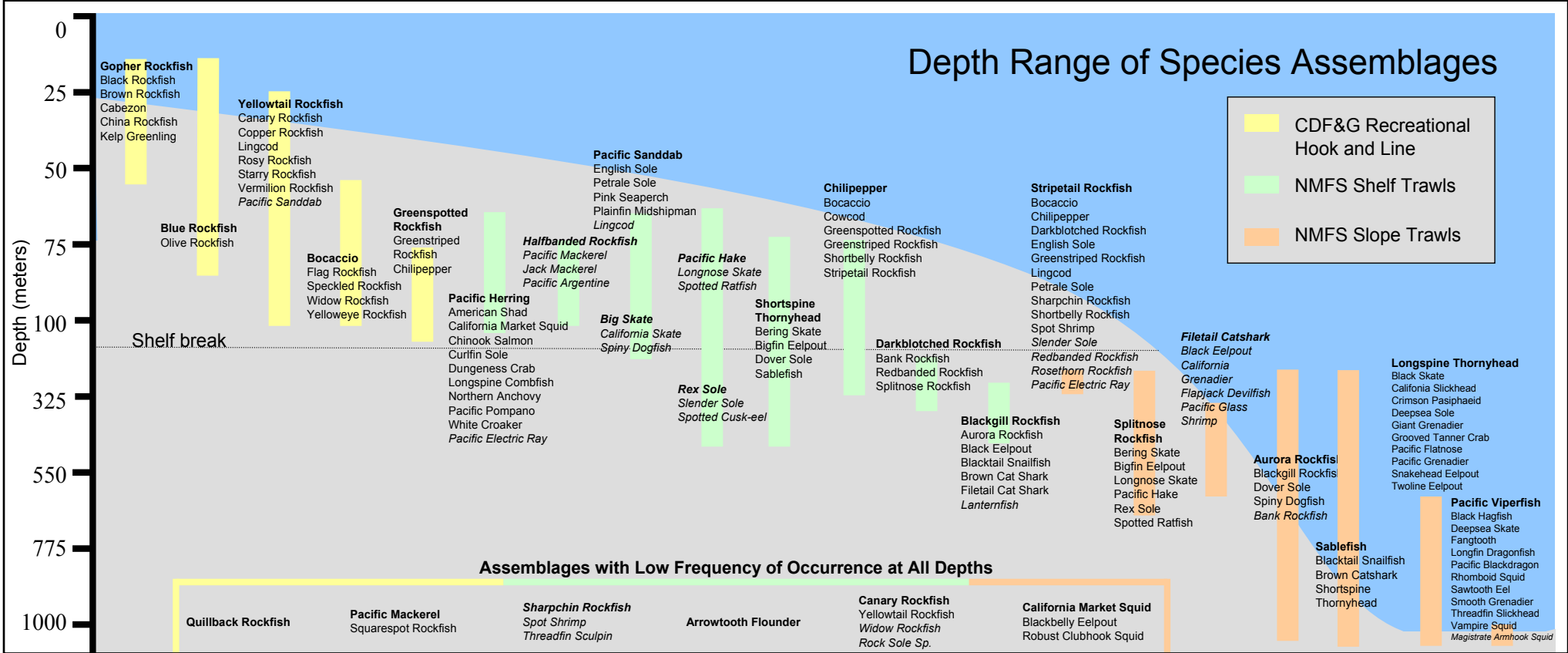


Figure 29. Overlap between the three data sets that analyzed demersal fish: CDF&G recreational (yellow), NMFS shelf (green), and NMFS slope (orange). The length of the vertical line depicts the depth interval where species assemblages had an average frequency of occurrence in at least 25% of the trawls (see Tables 2,4,6-8). Non-italicized species were consistently placed into the same species assemblage; italicized species tended to roam into other assemblages with random sampling.

Subsection 2.1.1: ASSEMBLAGE ANALYSES

REFERENCES

Baraff L.S. and T.R. Loughlin. 2000. Trends and potential interactions between pinnipeds and fisheries of New England and the U.S. West Coast. *Mar. Fish. Rev.*, Vol62, pp.1-39.

Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. Special Scientific Report No. 77, EPA-600/3-77-033. Virginia Institute of Marine Science, Williamsburg, VA. 114 pp.

Brown, S.K., K.R. Buja, S.H. Jury, and M.E. Monaco.2000. Habitat suitability index models for eight fish and invertebrate species in Casco and Sheepscot Bays, Maine. *N. Amer.J. Fish. Mgmt.*, Vol. 20, pp. 408-435.

Cailliet, G.M., K.A. Karpov, and D.A. Ambrose. 1979. Pelagic assemblages as determined from purse seine and large midwater trawl catches in Monterey Bay and their affinities with the market squid, *Loligo opalescens*. *CalCOFI Rep.*, Vol. 20, pp. 21-30.

Carr, M.H. 1991. Habitat selection and recruitment of an assemblage of temperate zone reef fishes. *J. Exp. Mar. Biol. Ecol.*, Vol. 146, pp. 113-137.

Chavez, F. P, J. Ryan, S. E. Lluch-Cota, and M. Ñiquen. 2002. From anchovies to sardines and back: Multidecadal change in the Pacific Ocean. *Science*, Vol 299, pp. 217-221.

Estes, J.A., M.T. Tinker, T.M. Williams, and D.F. Doak. 1998. Killer whale predation on sea otters linking oceanic and nearshore ecosystems. *Science*, Vol 282, pp.473-476.

Field, J.M., M.M. Yoklavich, J. deMarignac, G.M. Cailliet, R. N. Lea, and S.M. Bros. 2002. Small-scale analysis of subtidal fish assemblages and associated habitat characteristics off Central California in Marine Ecological Reserves Research Program: research results 1996-2001. California College Sea Grant Program CD-Rom, La Jolla, CA, www.csgc.ucsd.edu. 16 pp.

Gabriel, W.L. and A.V. Tyler. 1980. Preliminary analysis of Pacific Coast demersal fish assemblages. *Mar. Fish. Rev.*, Vol. 42(3-4), pp. 83-88.

Gauch, H.G. Jr. 1982. Multivariate analysis in community ecology. Cambridge Univ. Press, New York.

Hallacher, L.E. and D.A. Roberts. 1985. Differential utilization of space and food by the inshore rockfishes (Sebastes) of Carmel Bay, California. *Env. Biol. Fish.*, Vol. 12(2), pp. 91-110.

Hixon, M.A., B.N. Tissot, and W.G. Pearcy. 1991. Fish assemblages of rocky banks of the Pacific Northwest: final report. Minerals Management Service, MMS 91-0052. Camarillo, California. 410 pp.

Hixon, M.A., and B.N. Tissot. 1992. Fish assemblages of rocky banks of the Pacific Northwest: supplement. Minerals Management Service MMS 92-0025. Camarillo, California. 128 pp.

Horn, M.H. and L.G. Allen. 1978. A distributional analysis of California coastal marine fishes. *J. Biogeog.*, Vol. 5, pp. 23-42.

Jay, C.V. 1996. Distribution of bottom-trawl fish assemblages over the continental shelf and upper slope of the U.S. west coast, 1977-1992. *Can. J. Fish. Aquat. Sci.*, Vol. 53, pp.1203-1225.

Larson, R.J., W.H. Lenarz, and S. Ralston. 1994. The distribution of pelagic juvenile rockfish of the genus *Sebastes* in the upwelling region off central California. *CalCOFI Rep.*, Vol. 35, pp. 175-221.

Lauth, R.R. 2001. The 2000 Pacific west coast upper continental slope trawl survey of groundfish resources off Washington, Oregon and California: estimates of distribution, abundance, and length composition. NOAA Tech. Memo. NMFS-AFSC-120. Silver Spring, MD. 284 pp.

Lenarz, W.H., R.J. Larson, and S. Ralston. 1991. Depth distributions of late larvae and pelagic juveniles of some fishes of the California Current. *Calif. Coop. Oceanic Fish. Invest. Rep.*, Vol. 32, pp. 41-46.

Loeb, V., M. Yoklavich, and G. Cailliet. 1994. California Sea Grant biennial report of completed projects, 1992-1994. Moss Marine Laboratories: La Jolla, CA. Pp. 79-95.

Love, M.S., J.E. Caselle, and W.V. Buskirk. 1998. A severe decline in the commercial passenger fishing vessel rockfish (*Sebastes* spp.) catch in the southern California Bight, 1980-1996. *CalCOFI Rep.*, Vol. 39, pp. 180-195.

Love, M. S. 1996. Probably more than you want to know about the fishes of the Pacific Coast. Santa Barbara, Calif.: Really Big Press. 88 pp.

Love, M.S., M.M. Yoklavich, and L. Thorsteinson. 2002. The rockfishes of the northeast Pacific. University of California Press, Berkeley and Los Angeles, CA. 404 pp.

Mason, J.E. 1995. Species trends in sport fisheries, Monterey Bay, California, 1959-86. *Mar. Fish. Rev.*, Vol. 57(1), pp. 1-16.

Mason, J.E. 1998. Declining rockfish lengths in the Monterey Bay, California, recreational fishery, 1959-94. *Mar. Fish. Rev.*, Vol. 60(3), pp. 15-28.

Matthews, K.R. and L.J. Richards. 1991. Rockfish (*Scorpaenidae*) assemblages of trawlable and untrawlable habitats off Vancouver Island, British Columbia. *N. Amer. J. Fish. Mgmt.*, Vol. 11, pp. 312-318.

McGarigal, K., S. Cushman, and S. Stafford. 2000. Multivariate statistics for wildlife and ecology research. Springer-Verlag, New York. 130 pp.

Moser, H.G. R. L. Charter, W. Watson, D. A. Ambrose, J. L. Butler, S. R. Charter, and E. M. Sandknop. 1999. Abundance and distribution of rockfish (*Sebastes*) larvae in the Southern California Bight in relation to environmental conditions and fishery exploitation. *CalCOFI Rep.*, Vol. 41, pp. 132-147.

National Marine Fisheries Service. 2001. Endangered Species Act. Section 7 Consultation - Biological opinion on authorization of Gulf of Alaska and Bering Sea/ Aleutian Islands groundfish fisheries based on the Fishery Management Plan for the Gulf of Alaska and Bering Sea/ Aleutian Islands groundfish as modified by amendments 61 and 70. NMFS-Alaska Region, Protected Resources Division, Silver Spring, MD.

National Marine Fisheries Service. 2002. Magnuson-Stevens Act Provisions. http://www.nwr.noaa.gov/1sustfsh/groundfish/proposed_rule.pdf. Federal Register, Vol. 67(8), 1582 pp

Paukert, C.P. and T.A. Wittig. 2002. Applications of multivariate statistical methods in fisheries. *Fisheries*, Vol. 27(9), pp. 16-22.

Ralston, S. 1998. The status of federally managed rockfish on the U.S. West Coast in Marine harvest refugia for West Coast rockfish: A workshop. NOAA-TM-NMFS-SWFSC-255. Pacific Grove, California. 11 pp.

Shannon, C.E., and W. Weaver. 1949. The mathematical theory of communication. University of Illinois Press, Urbana, IL. 125pp.

Shaw, F.R., Wilkins, M.E., Weinberg, K.L., Zimmermann, M., and R.R. Lauth. 2000. The 1998 Pacific west coast bottom trawl survey of groundfish resources: estimates of distribution, abundance, and length and age composition. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-114. Silver Spring, MD. 138 pp.

Starr, R.M. 1998. Marine harvest refugia for West Coast rockfish: A workshop. NOAA-TM-NMFS-SWFSC-255. Pacific Grove, California.14pp.

Starr, R.M, J.M. Cope, and L. A. Kerr. 2002. Trends in fisheries and fishery resources associated with the Monterey Bay National Marine Sanctuary from 1981-2000. California Sea Grant College Program Publication No. T-046. Monterey, CA. 156 pp.

Sullivan, C.M. 1995. Grouping of fishing locations using similarities in species composition for the Monterey Bay area Commercial Passenger Fishing Vessel Fishery, 1987-1992. California Department of Fish and Game, Marine Resources Technical Report No. 59. Monterey, CA. 37 pp.

Turk, T. A., T. Builder, C. W. West, D. J. Kamikawa, J. R. Wallace, R. D. Methot, A. R. Bailey, K. L. Bosley, A. J. Cook, E. L. Fruh, B. H. Horness, K. Piner, H. R. Sanborn, and W. W. Wakefield. 2001. The 1998 Northwest Fisheries Science Center Pacific west coast upper continental slope trawl survey of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, and length composition. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-50. Seattle, WA. 122 pp.

Weinberg, K.L., M.E. Wilkins, F.R. Shaw, and M. Zimmermann. 2002. The 2001 Pacific west coast bottom trawl survey of groundfish resources: Estimates of distribution, abundance, and length and age composition. U. S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-128. Seattle, WA. 140pp.

Williams, E.H. and S. Ralston. 2002. Distribution and co-occurrence of rockfishes over trawlable shelf and slope habitats of California and southern Oregon. *Fish. Bull.*, Vol. 100, pp. 836-855.

Wilkins, M.E., M. Zimmerman, and K.L. Weinberg. 1998. The 1995 Pacific west coast bottom trawl survey of groundfish resources: Estimates of distribution, abundance, and length and age composition. NOAA Tech. Memo NMFS-AFSC-89. Seattle, WA. 138 pp.

Wilson-Vandenberg, D., P.N. Reilly, and C.E. Wilson. 1996. Onboard sampling of the rockfish and lingcod commercial passenger fishing vessel industry in northern and central California, January through December 1994. Marine Resources Division Administrative Report No. 96-6. San Francisco, CA. 96 pp.

Worm, B. and R. A. Myers. 2003. Meta-analysis of cod-shrimp interactions reveal top-down control in oceanic food webs. *Ecology*, 84(1), pp. 162-173.

Yoklavich, M.M., H.G. Greene, G.M. Cailliet, D.E. Sullivan, R.N. Lea, and M.S. Love. 2000. Habitat associations of deep-water rockfishes in a submarine canyon: An example of a natural refuge. *Fish. Bull.*, Vol. 98, pp. 625-641.

Yoklavich, M.M., V.J. Loeb, M. Nishimoto, and B. Daly. 1996. Near-shore assemblages of larval rockfishes and their physical environment off central California during an extended El Niño event, 1991-1993. *Fish. Bull.*, Vol. 94, pp. 766-782.

Yoklavich, M.M, G.M. Cailliet, R.N. Lea, H.G. Greene, R.M. Starr, J. de Marignac, and J. Field. 2002. Deepwater habitat and fish resources associated with a marine reserve: implications for fisheries. Marine Ecological Reserves Research Program Research Results 1996-2001. California College Sea Grant Program CD-Rom. www.csgc.ucsd.edu. La Jolla, CA. 63 pp.

Zar, J.H. 1999. Biostatistical Analysis, fourth edition. Prentice-Hall, Inc. Upper Saddle River, New Jersey. 80 pp.

Zimmerman, M., M.E. Wilkins, K.L. Weinberg, R.R. Lauth, and F.R. Shaw. 2001. Retrospective analysis of suspiciously small catches in the National Marine Fisheries Service West Coast Triennial Bottom Trawl Survey. Alaska Fisheries Science Center Processed Report, 2001-3. Anchorage, AK. 135 pp.

Subsection 2.1.2: HABITAT SUITABILITY MODELING

INTRODUCTION

Habitat suitability modeling (HSM) is a tool for predicting the suitability of habitat for a given species based on known affinities with environmental parameters. This technique was chosen for this project to provide a synoptic view of habitat suitability for specific species as well as assess habitat suitability for species assemblages. One HSM technique is termed “habitat suitability index (HSI) modeling”. HSI models are simple mathematical expressions for calculating a unitless index of habitat quality as a function of one or more environmental variables. Using GIS, these index values can be mapped and analyzed to portray areas of potential distribution for a species (Brown et al., 2000) (Figure 30). High-quality habitat may provide high carrying capacity and support higher rates of growth, survival, or reproduction for a given species, whereas low-quality or unsuitable habitat may have little or no carrying capacity (Brown et al., 2000). The HSI methods were adapted from the U.S. Fish and Wildlife Service (USFWS) Habitat Evaluation Procedures program (USFWS, 1980a, 1980b, 1981) to provide spatially explicit estimates of suitability across the entire study area. It is important to note that the model results depict potentially suitable habitat for a given species and not actual distribution. This section provides the methodology, results, validation, and interpretation of HSI models developed for selected adult and subadult stages of commercially and recreationally important groundfish and invertebrate species. The models are based on species’ affinities to substrate types and bathymetric ranges (Monaco et al., 1998).

DATA AND ANALYSES

Environmental Data: Initially bathymetry, benthic substrate type, and bottom temperature were chosen as the environmental data to be included in the models. Although water temperature is an influential factor that affects species distributions and movement, several factors led to the exclusion of bottom temperature from final model development: 1) information regarding species associations with bottom temperature were too general or absent from scientific literature; 2) statistical analyses revealed collinearity between bottom temperatures collected with NMFS trawl samples and bathymetry; and 3) since most of the species modeled are benthic organisms where bottom temperature is not highly variable, numerous authors state that depth is the most significant factor regulating species distributions (Gabriel and Tyler, 1980; Matthews and Richards, 1991; Yoklavich et al., 2000; Williams and Ralston, 2002). As a result, water temperature was eliminated as a modeling variable. This does not preclude using water temperature as a variable for modeling pelagic species, however, more information will have to be collected to explore their affinities for this variable. Based on these considerations, bathymetry and substrate data were used to map HSI model results. Numerous data sources were combined to produce a digital, high resolution map of bathym-

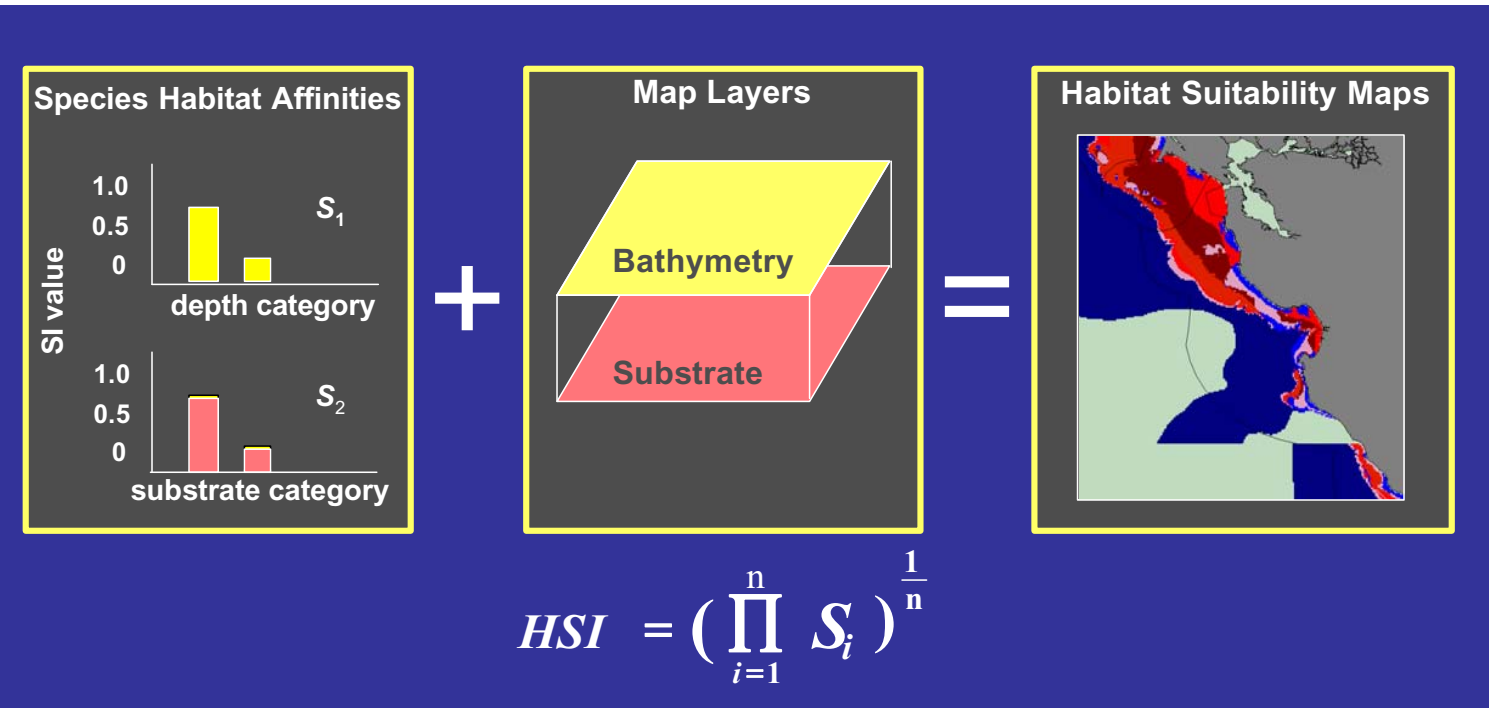


Figure 30. Species habitat suitability modeling approach.

etry. Bathymetry was rasterized with 70 m cell size for most of the study area for depths to 4810 m. Benthic substrate was mapped from Point Arena in the north to Point Sal in the south to conform to the latitudinal limits of the study area. Substrates were characterized using 5 classifications: sand, mud, rock, pebble/cobble/gravel, and mud/rock mix.

Species selected for HSM: The primary criteria to select species for which HSMs were developed was their commercial and ecological importance. In addition, several species were included based on recommendations by staff members from the NMSP. Overall, 20 species were modeled, 14 of which included models for adult and subadult distribution. Species with two life stage models include: bocaccio, canary rockfish, chilipepper rockfish, darkblotched rockfish, longspine thornyhead, shortspine thornyhead, lingcod, sablefish, Pacific whiting (hake), dover sole, english sole, petrale sole, rex sole, and Pacific sanddab. Potential adult distributions were modeled for Dungeness crab, California market squid, blue rockfish, widow rockfish, yelloweye rockfish, and yellowtail rockfish. Some of these species were chosen to represent species assemblages as determined in Section 2.1.1, and mapped to display the potential distribution of suitable habitats for the assemblage. For example, cluster analyses determined that Dover sole, sablefish, and shortspine thornyhead were commonly captured in NMFS trawl surveys, indicating a deep water shelf assemblage for these species.

HSI Data/SI Development: Initially, suitability index (SI) values for bathymetry and substrate type were developed through literature review and modeled in GIS. During October 2002, the methodological approach and results were peer-reviewed by NMSP and NMFS staff who suggested that, where sufficient data were available, bathymetry SI values should be developed using NMFS trawl data. In addition, the panel requested separate models for adults and juveniles. As a result, a subset of NMFS trawl data on the shelf (1977-1995) and slope (1984-1999) for the entire west coast were used to develop SI values for adults and juveniles for most species. SI values for bathymetry were developed from NMFS trawl data by fitting a polynomial regression to bathymetric classes and mean species abundance (log transformed) (Figure 31). Since trawl samples were not collected in waters less than 50 m, the bathymetric classes begin at 50 m with a range of 20 m between classes. The fitted curve was weighted by sampling effort to account for disproportionate sample sizes within bathymetric classes. Predicted mean abundance along the curve was then used to calculate SI's for each bathymetric class by dividing each mean abundance value by the

maximum observed across the bathymetric gradient (Table 9) (Rubec et al., 1999). Resultant values were multiplied by 10 to scale SI's by whole integers (0-10), as reclassification of environmental grids is done using ArcView which does not recognize decimals. For species that had limited or no trawl data, SI values were developed from bathymetric ranges reported in the literature (Christensen et al., 1997; Brown et al., 2000). Table 10 displays a sample data matrix generated from literature sources, where presence (1) or absence (0) is coded within the bathymetric classes for each particular species and life stage. In this technique, the total number of references that denote presence of the species are summed within each depth class and then divided by the total number of references examined to obtain the final SI value. Literature review provided only general ranges of species occurrence in relation to bathymetry, therefore, classes of 50 m were chosen to confidently develop SI values rather than the 20 m classes used above. Differentiating depth ranges for adults and juveniles from literature sources was difficult due to lack of data, therefore, only adult SI values could be developed using this technique. SI's for affinities with substrate were also created using this technique. SI's for juveniles based on bathymetry were developed using NMFS trawl data, when available, or were simply not modeled where trawl data was limited or absent. Contrasting evidence exists within the literature that bathymetric preferences can shift for many groundfish species based on latitude (PFMC, 1999; Williams and Ralston, 2002). For the present study, it was assumed that depth preference was similar regardless of latitude, although further exploration into this reported trend is currently underway. Similarly, preference for substrate was assumed to be the same throughout each species' range.

The NMFS trawls were conducted in depths of 50 – 1300 m; therefore bathymetric SI's outside this range could not be calculated. Depth information within the literature exists for

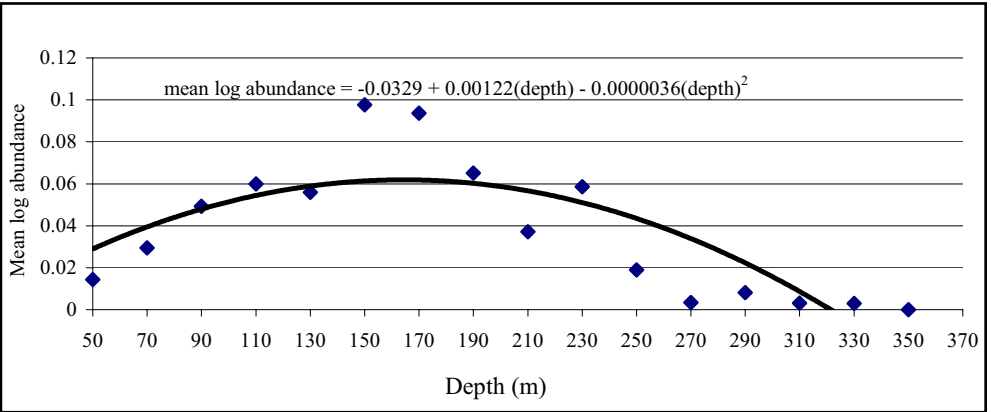


Figure 31. Polynomial regression curve fit with mean log abundance by categorical bathymetric class for subadult bocaccio.

Subsection 2.1.2: HABITAT SUITABILITY MODELING

Table 9. Example data matrix for calculating bathymetry SI values for subadult bocaccio taken in NMFS trawl samples (Rubec et al., 1999).

Depth Class (m)	Effort (# of samples)	Mean log abundance	Predicted mean log abundance (x)	HSI (x/xmax)*10
50-69	219	.014	.019	3
70-89	361	.029	.035	5
90-109	447	.049	.048	7
110-129	489	.060	.058	8
130-149	398	.056	.065	9
150-169	252	.100	.069	10
170-189	200	.094	.070	10
190-209	213	.065	.069	10
210-229	182	.037	.064	9
230-249	98	.059	.057	8
250-269	92	.019	.047	7
270-289	89	.003	.034	5
290-309	74	.008	.018	3
310-329	98	.003	0	0
330-349	52	0	0	0

Table 10. Example presence/absence information and SI calculation from scientific literature.

Source	Depth Class (m)							
	50-99	100-149	150-199	200-249	250-299	300-349	350-399	400-449
A	1	1	0	0	0	0	0	0
B	1	1	1	0	0	0	0	0
C	1	1	1	1	1	0	0	0
D	1	1	1	1	1	0	0	0
Sum	4	4	3	2	2	0	0	0
SI=Sum/Total References*10	10	10	7	5	5	0	0	0

most species outside of this range, but was omitted from modeling and mapping to match the depth range associated with the NMFS trawls. Trawls were conducted during June to November, thus models for different “seasons” could not be created. Therefore, modeled map surfaces represent species potential distributions for water depths from 50-1300 meters and for the summer and late fall time period. Also, many of the species modeled exhibit inshore/offshore migrations based on habitat shifts associated with life history requirements and/or spawning activity. Additional data will have to be collected to reflect these shifts in abundance and distribution; thusly, no attempt was made to model them here.

HSI Results-Mapping: Once SI values were determined for bathymetry and substrate type, these values were inserted into the environmental grids. Once each species’ suitability indices were derived (either through regression or through the literature), the values were combined with the bathymetry and substrate map layers to calculate an index of habitat suitability. The habitat suitability was calculated as the geometric mean of suitability indices (S_i) for the two (n) environmental factors (Rubec et al. (1999) (Figure 30):

$$HSI = (\prod_{i=1}^n S_i)^{\frac{1}{n}}$$

The resulting maps display the potential suitability of cells for each species based on the strength of their affinities to depth and substrate type in each cell. The map displays habitat suitability in a unitless index from 0 (unsuitable) to 10 (highly suitable).

Validation of HSI Model: The remaining subsets (i.e. independent data) of NMFS trawl data from the shelf (1998-2001) and slope (2000-2001) were used to assess model performance. Mean abundance was calculated for each species from these data and superimposed over the predicted HSI values and compared by regressing observed catch data on the predicted HSI values. The statistical results are not intended to be definitive tests of the model, but provide supporting evidence for the existence and strength of the relationship between the model predictions and the catch data. It is important to note that these models are based on two independent parameters and are not the definitive predictors of habitat utilization for these species. Fishery-dependent data from CDF&G recreational surveys were also used to validate models for species that had limited trawl information, i.e. species that display affinities for rocky substrates (rockfishes) and had poor representation in trawl data. If the model performs correctly, this validation procedure should demonstrate increasing mean abundance with increasing habitat suitability.

Integrative Maps: Management plans are often developed for a group of species that exhibit similar life history strategies. Selected species assemblages, as defined in Section 2.1.1, were analyzed and mapped to identify the spatial distribution of their important habitats. In addition, two analyses were conducted (page 42) which examine the overlap of highly suitable habitat based on all species for which HSI maps were developed. Areas with the most overlap of high suitability could be considered important habitats for selected groundfish.

ANALYTICAL MAP PRODUCTS

As part of the biogeographic assessment, digital data were developed as products from the study. Digital bathymetry and substrate maps were created as ArcView shape and raster files. Maps of these environmental data can be seen on pages 36-37, while digital files are located on the accompanying CD-ROM. Three representative HSI models are presented: bocaccio (adult and subadult), Dover sole (adult and subadult), and Dungeness crab (adult). The remaining 31 species’ HSI maps are on the CD-ROM. Representative maps displaying habitat importance based on all HSI models and select species assemblages are also included. Additional integrative maps for shelf assemblages, all rockfish, and all flatfish, are also included on the CD-ROM.



Kip Evans

Subsection 2.1.2: HABITAT SUITABILITY MODELING

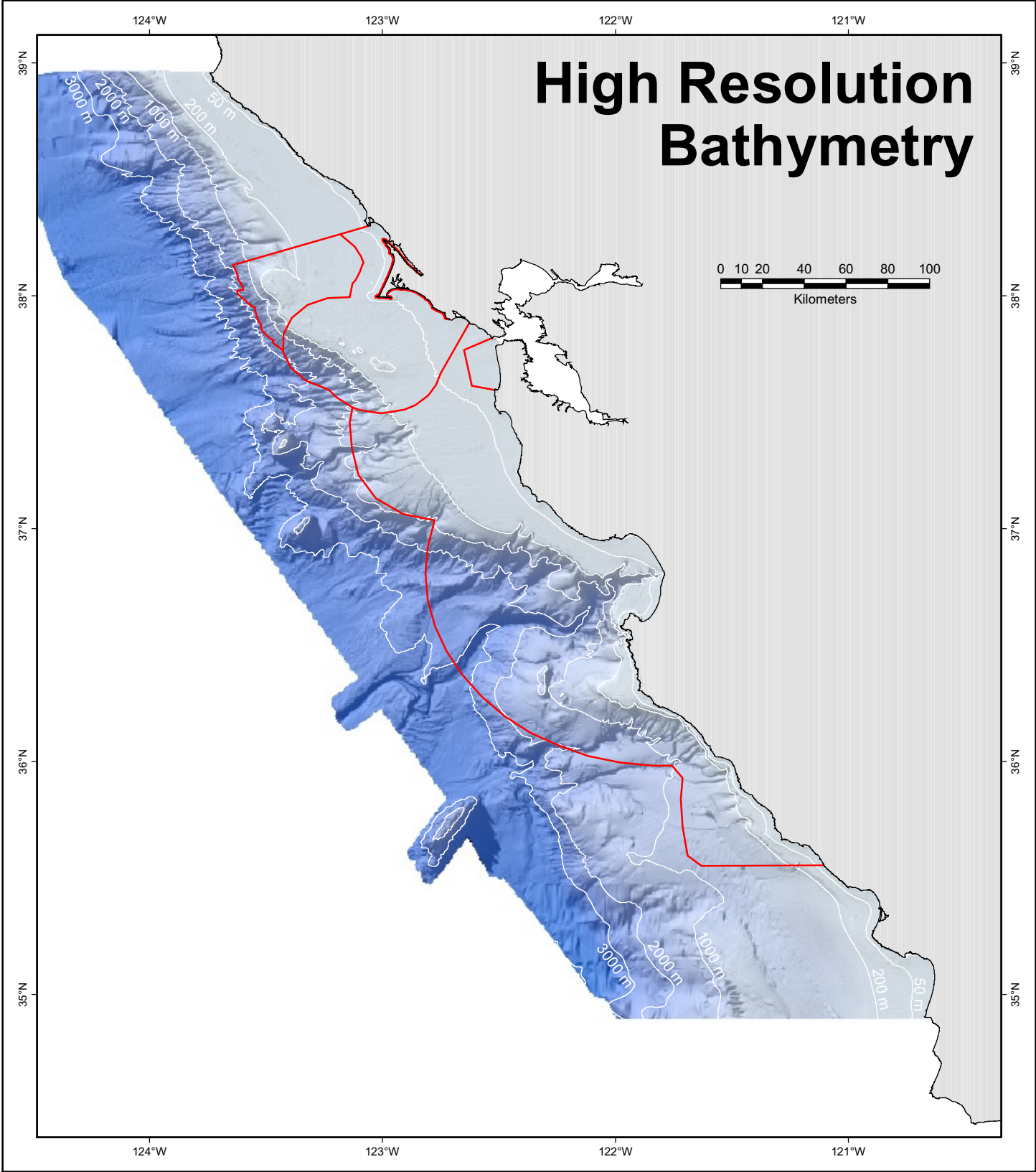


Figure 32. Bathymetric map for the north/central California study area. Red lines indicate National Marine Sanctuary boundaries.

ABOUT THIS MAP

Figure 32 displays a bathymetric model of the north/central California study area. Prominent bottom features, such as canyons, seamounts, banks, and other large scale geological formations, are evident at the scale presented.

DATA SOURCES

NOAA/NOS hydrographic survey data available from the National Geodetic Data Center (NGDC) and Monterey Bay Research Institute (MBARI) – multibeam data.

METHODS

Results were calculated from 3 arc second bathymetry (nominally 70 m) derived from NGDC and MBARI data sources. All available multibeam data were used. Hydrographic survey data (echo soundings) were eliminated from the calculation if it occurred coincidentally with multibeam information. Vertical and horizontal correction was performed on all data prior to modeling. All data were triangulated and rasterized using Vertical Mapper extension of MapInfo 6.5. Cell size varied throughout the study area, but significant portions were mapped at 70 m² grid cell resolution.

RESULTS AND DISCUSSION

The study area contains two distinct bathymetric regions. The northern portion of the study area, from Monterey Canyon northward, is characterized by having a broad continental shelf (15-50 km wide), while the southern region has a very narrow shelf with rapidly increasing depth close to shore. This pattern results in significantly shallower mean depth for Cordell Bank (394.9 m) and Gulf of the Farallones (265.3 m) sanctuaries compared to the mean depth within Monterey’s sanctuary (876.9 m). For a more detailed description of bathymetric features see the explanation of the study area on page 1.

This map is not intended for navigational purposes. Some areas on this map are created from old or sparse data, and are not necessarily representative of the actual seafloor characteristics.



Subsection 2.1.2: HABITAT SUITABILITY MODELING

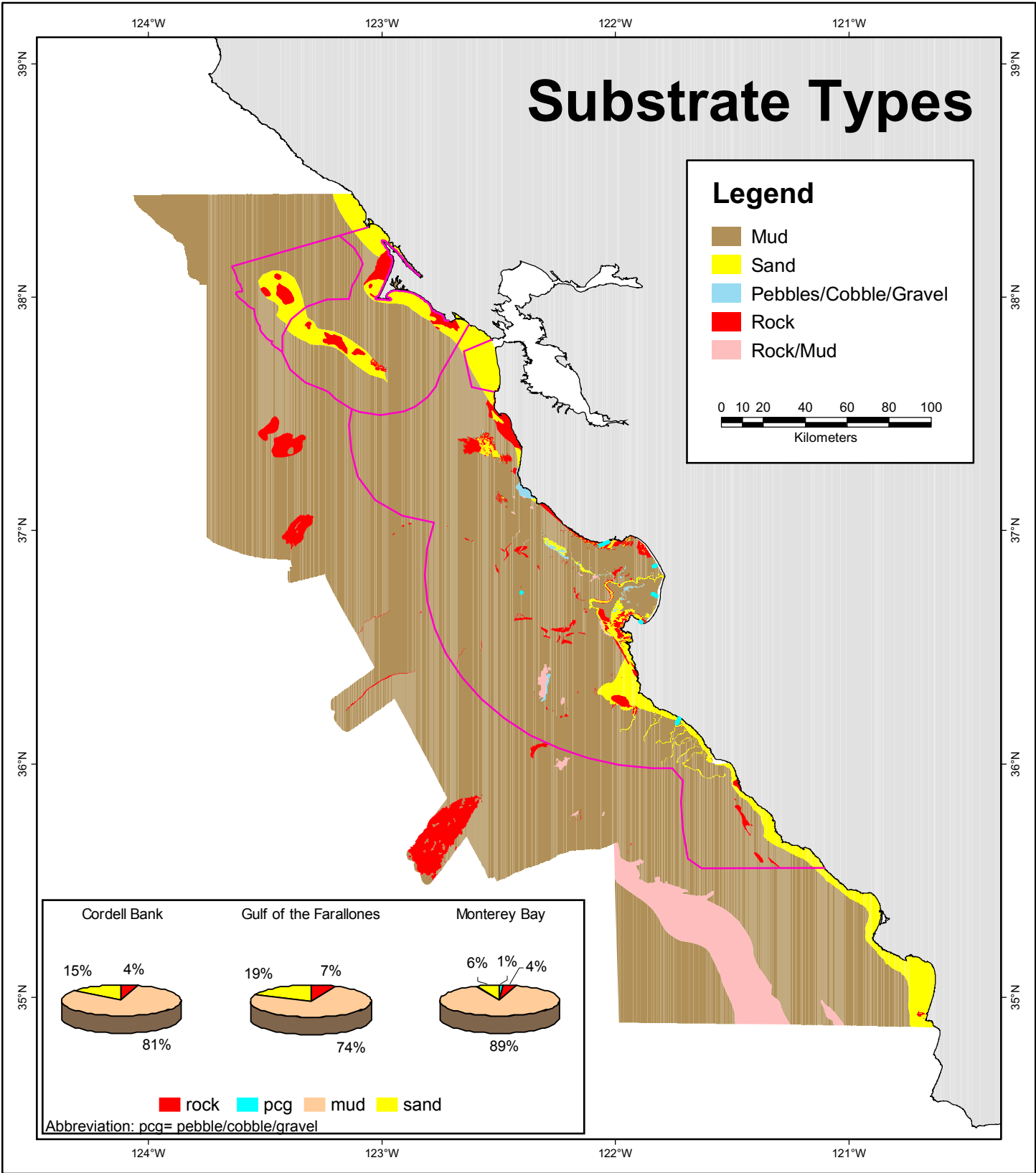


Figure 33. Substrate types for the north/central California marine region.

ABOUT THIS MAP

Figure 33 displays distribution of substrate types throughout the study area, from Point Arena to Point Sal California. The substrate is classified into 5 categories: mud, sand, pebbles/cobbles/gravel (pcg), rock, and mud/rock mix.

DATA SOURCES

California Continental Margin Geologic Map Series (Maps 4-6) (Greene and Kennedy, 1989). These maps were originally created with a 1:250,000 resolution and were used as the basemaps for recent revisions and incorporation of new high resolution multibeam data in small portions of the study area.

METHODS

Initially, seven maps were developed that displayed substrate type and geologic formations throughout California's coastal and marine environments. The original data were compiled by the California Division of Mines and Geology, USGS, and California Coastal Commission to produce paper maps. Geologists from California State University-Monterey Bay digitized these maps in 1999 and further interpreted these data to develop boundaries of substrate types (Greene et al., 1999). Three of the seven maps provide data for the study area and together provide the most comprehensive map of substrate type for the north/central California marine and near-shore region. For a detailed description of the development of the original maps and classification scheme, refer to Greene et al., 1999 and Greene et al., 2002. Eight substrate types were classified, however, some were grouped together when the digital substrate shapefile was rasterized into 1 km² grid cells to facilitate their use in the HSI model analyses (See Section 2.1.2). "Boulders" and "Hard/Anthropogenic" polygons were grouped within the "Rock" substrate type, and "Gravel" was grouped with "Cobbles/Pebbles" because boulder and gravel polygons were limited in number and affinities to these were considered to be similar to the group it was reclassified with.

RESULTS AND DISCUSSION

The substrate map covers an area of approximately 44,000 km², of which mud accounts for 86.4% (38,023 km²) of the total bottom area. Substrate containing pebble/cobble/gravel were the least abundant substrate types, only encompassing 100 km² of the study area. Rock substrates were mostly patchy throughout the region, encompassing 1,561 km². Mud and rock mixed substrate (1,706 km²) was almost exclusively distributed in the southern portion of the study area, with small localized areas near Monterey canyon. Sand (2,611 km²) is predominantly located near-shore with a large area located near and around Cordell Bank. Within sanctuary boundaries, soft sediments (mud, sand) account for almost 95% of the substrate. Rocky areas (including pebbles, cobbles, gravel) account for approximately 5%, while less than 1% consists of

mud/rock mix. Within sanctuary boundaries, rocky substrates are distributed predominantly on the shelf, occurring in the areas near Cordell Bank, Farallone Islands, in many near-shore areas, and scattered within Monterey Bay. Outside sanctuary boundaries, several large areas of rock are found on the slope in depths greater than 1200 m. Mixed rock/mud substrate is scarce within the study area, with most occurring southwest of Monterey canyon. One large area of mixed rock/mud is present southwest of the southern Monterey Sanctuary boundary. Areas containing pebble, cobble, and gravel are found exclusively in Monterey's sanctuary and are generally found within depths of 100-200 m. The majority of sand substrate is found near-shore in the northernmost and southernmost portions of the study area, with significant coverage also occurring around Cordell Bank. Figure 33 displays the percent coverage of bottom types within each sanctuary. Other important substrate types exist within the study area, such as near-shore kelp beds, but were not included in the map based on their ephemeral distribution and the limitations associated with development of bathymetric SI's in near-shore areas.

Although the substrate map is a probabilistic map of substrate types, it reflects the most complete and current knowledge of benthic substrates for the north/central California region. The map alone can be used to support investigations that require advanced knowledge of sea floor type. In addition, the maps are useful identifications of critical or important habitats for particular species or for determining essential fish habitat that can aid conservation and management plans for fisheries species. In this study, the map was primarily used as an environmental layer in GIS (in addition to bathymetry) to determine habitat suitability for groundfish species. This approach assumes that the underlying environmental GIS layers are an accurate representation of that particular variable, thus the model results are only as good as the underlying digital information. The substrate map is conservative, based on its original scale (1:250,000), and may have fine scale inaccuracies throughout the study area. The majority of this map has not been field tested; therefore, inaccuracies in classification may exist. For example, several small polygons classified as rock near Point Reyes have been questioned. HSM results presented herein do not contain these polygons due to depth limitations with the fish and invertebrate catch data (50-1300 m). Small localized areas of high resolution information (on the scale of 10's of meters) have been included in this map, however, these areas comprise a small percentage of the overall study area. More information is required to test the accuracy of the map; hence, thematic accuracy of substrate types is unknown.

Subsection 2.1.2: HABITAT SUITABILITY MODELING

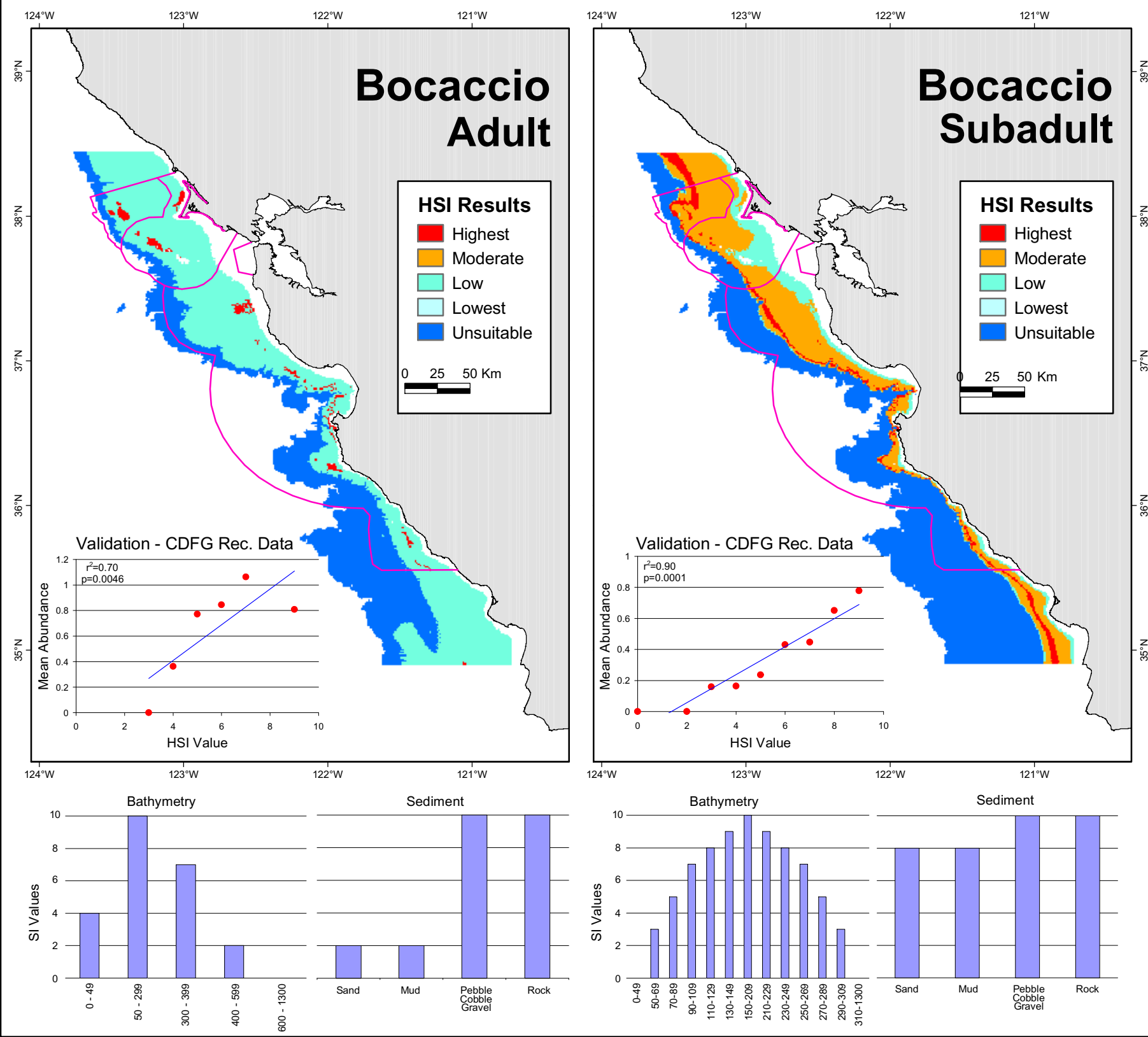


Figure 34. Potential distribution of habitat suitability for adult and subadult bocaccio. Map inset contains validation statistics. SI values for bathymetry and substrate are graphically displayed below the map.

ABOUT THESE MAPS

Figure 34 displays HSI model results for adult (left) and subadult (right) bocaccio during June-November. The maps exhibit the potential distribution of the species based on affinities to bathymetry and substrate. Predicted HSI values range in scale from 10 (highest) to 0 (unsuitable) and were grouped into five classes: highest suitability (10-8), moderate (7-5), low (4-2), lowest (1), and unsuitable (0). SI values for bathymetry and substrate type are shown in the graphics below the mapped HSI results. Model performance graphics and statistical details are displayed in the map insets.

DATA SOURCES

Bathymetry SI: Alverson et al., 1964; Feder et al., 1974; Dark et al., 1983; Gunderson and Sample, 1980; Tagart and Kimura, 1982; Eschmeyer et al., 1983; Allen and Smith, 1988; Love et al., 1990; Wolotira et al., 1993; Wilkins et al., 1998; Yoklavich et al., 2000; Lauth, 2001; and Love et al., 2002.

Substrate SI: Feder et al., 1974; Eldridge, 1994; Yoklavich et al., 2000; and Love et al., 2002. Validation: Wilson-Vandenberg et al., 1996; Wilkins et al., 1998; and Turk et al., 2001.

Life stage information: Love et al., 2002.

METHODS

Bathymetry SI values for adult bocaccio were developed using the literature review method, whereas subadult SI values were assigned based on the regression fitting technique using NMFS trawl data.

RESULTS AND DISCUSSION

Length at maturity information (Love et al., 2002) was used to determine life stage for bocaccio. Adults were defined as: females >360 mm and males >350 mm total length. Depth suitability for subadults was highest from 90-270 m, while highest suitability for adults was similar, ranging from 50-299 m (Figure 34). Literature sources indicate that adult bocaccio are almost exclusively found around rocky substrates, while subadults exhibit broader affinity among substrate types (Figure 34). Comparison of the two HSM maps show that the marked difference in substrate preference for adults yields a more limited spatial distribution than subadults. Less than 5% of the available habitat within each sanctuary was predicted highly suitable (HSI values >8) for adult bocaccio (Cordell Bank – 4.6%, Gulf of Farallones – 2.9%, Monterey – 1.7%) Within the study area, habitat of high suitability occurs exclusively inside sanctuary boundaries. High suitability covers more area for subadults than adults and extends well beyond sanctuary boundaries. Nearly 10% of Cordell Bank's sanctuary was considered highly suitable for subadults. This percentage drops to 1.6% for Gulf of Farallones, and 2.6% for Monterey. Approximately 556 km² of potential high suitable habitat was located within the three sanctuaries, while an additional 355 km² were predicted outside sanctuary boundaries. Although the proportion of highly suitable habitats were similar for adults and subadults, large areas of potentially moderate suitability for subadults were observed throughout the study area; whereas no areas were predicted moderate for adults.

Generally, subadult bocaccio are more commonly found in shallower waters than adults (Love et al., 2002). Current scientific literature does not provide enough information to develop depth SI values for subadults; therefore, limited trawl information was used to develop SI values for bathymetry. Despite this, model performance for subadults yielded a strong positive correlation between observed abundance estimates from CDFG recreational catch data and predicted suitability (see map inset). Model performance for adult bocaccio also exhibited a strong positive correlation between predicted suitability and CDFG catch data. More information regarding bocaccio life history requirements are necessary to strengthen the HSI models; however, the mapped results and validation based on currently available information provide an adequate delineation of potential habitat suitability for adult and subadult bocaccio.

Subsection 2.1.2: HABITAT SUITABILITY MODELING

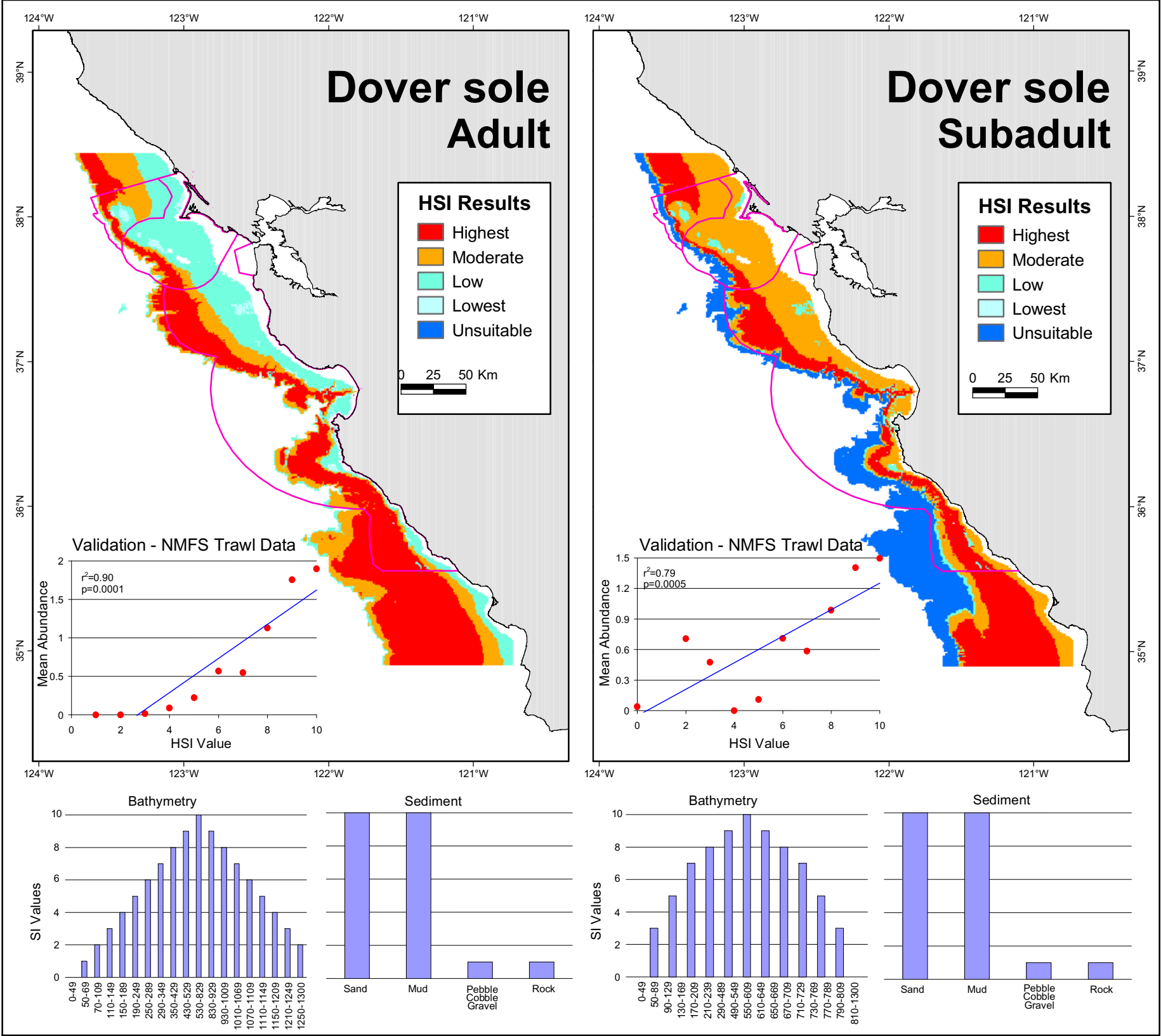


Figure 35. Potential distribution of habitat suitability for adult and subadult Dover sole. Map inset contains validation statistics. SI values for bathymetry and substrate are displayed below the maps.

ABOUT THESE MAPS

Figure 35 displays the HSI model results for adult (left) and subadult (right) Dover sole during June-November. The maps exhibit the potential distribution based on affinities to bathymetry and substrate. Predicted HSI values range in scale from 10 (highest) to 0 (unsuitable) and were grouped into five classes: highest suitability (10-8), moderate (7-5), low (4-2), lowest (1), and unsuitable (0). SI values for bathymetry and substrate type are shown in the graphics below the mapped HSI results. Model performance graphics and statistical details are displayed in the map insets.

DATA SOURCES

Bathymetry SI: Wilkins et al., 1998 and Lauth, 2001.
Substrate SI: Demory, 1975; Demory et al., 1976; Barss et al., 1977; Pearcy, 1978; NOAA, 1990; Stein et al., 1992; and CDFG, 2002.
Validation: Wilkins et al., 1998 and Turk et al., 2001.
Life stage information: PFMC, 1999.

METHODS

Bathymetry SI values for adults and subadults were developed from the regression fitting technique. Substrate SI values were developed through literature review.

RESULTS AND DISCUSSION

Adult Dover sole are reported to be >300 mm total length for male and female individuals (PFMC, 1999). Both adult and subadult Dover sole inhabit deep water slope habitats; subadults exhibited a shallower range of depth preference (130-650 m) than adults (290-1070 m) (Figure 35). Adults and subadults prefer soft sediments (sand and mud) throughout their range. Highest habitat suitability for subadults was predicted to occur along the shallower portions of the continental slope (200-550 m). A large area of moderate suitability was also predicted for an area that extends throughout the majority of the continental shelf. The most suitable habitats for adults consisted of deeper slope waters, with only moderate suitability extending onto the shelf region. Within Cordell Bank sanctuary, high subadult suitability (values 8-10) was calculated for 22% of the available habitat, 6.4% within Gulf of Farallones, and 19% within Monterey sanctuaries. Cordell Bank and Gulf of the Farallone sanctuaries are comprised of shallower (50-300m) shelf waters, thus the percentage of highly suitable habitat for adults is lower (based on their calculated affinity for deeper waters) than that observed for subadults (21% and 12%, respectively). However, Monterey's sanctuary is considerably deeper and a larger proportion of available habitats (30%) were predicted to be highly suitable for adults. Approximately 50% of areas that were predicted to be potentially suitable habitats for both adults and subadults occurred outside of sanctuary boundaries. These areas are most prominent south of Monterey's sanctuary.

Model performance was assessed by regressing predicted HSI values on mean log abundance values from NMFS trawl samples (1998-2001). Significant positive correlations were observed for both adult and subadult models, however, these are based on limited trawl samples (N = 311). Discrepancies in model performance, such as small peaks of mean abundance within low suitability areas, are a result of limited observations within that category. Additional trawl information would strengthen model development and performance.

Subsection 2.1.2: HABITAT SUITABILITY MODELING

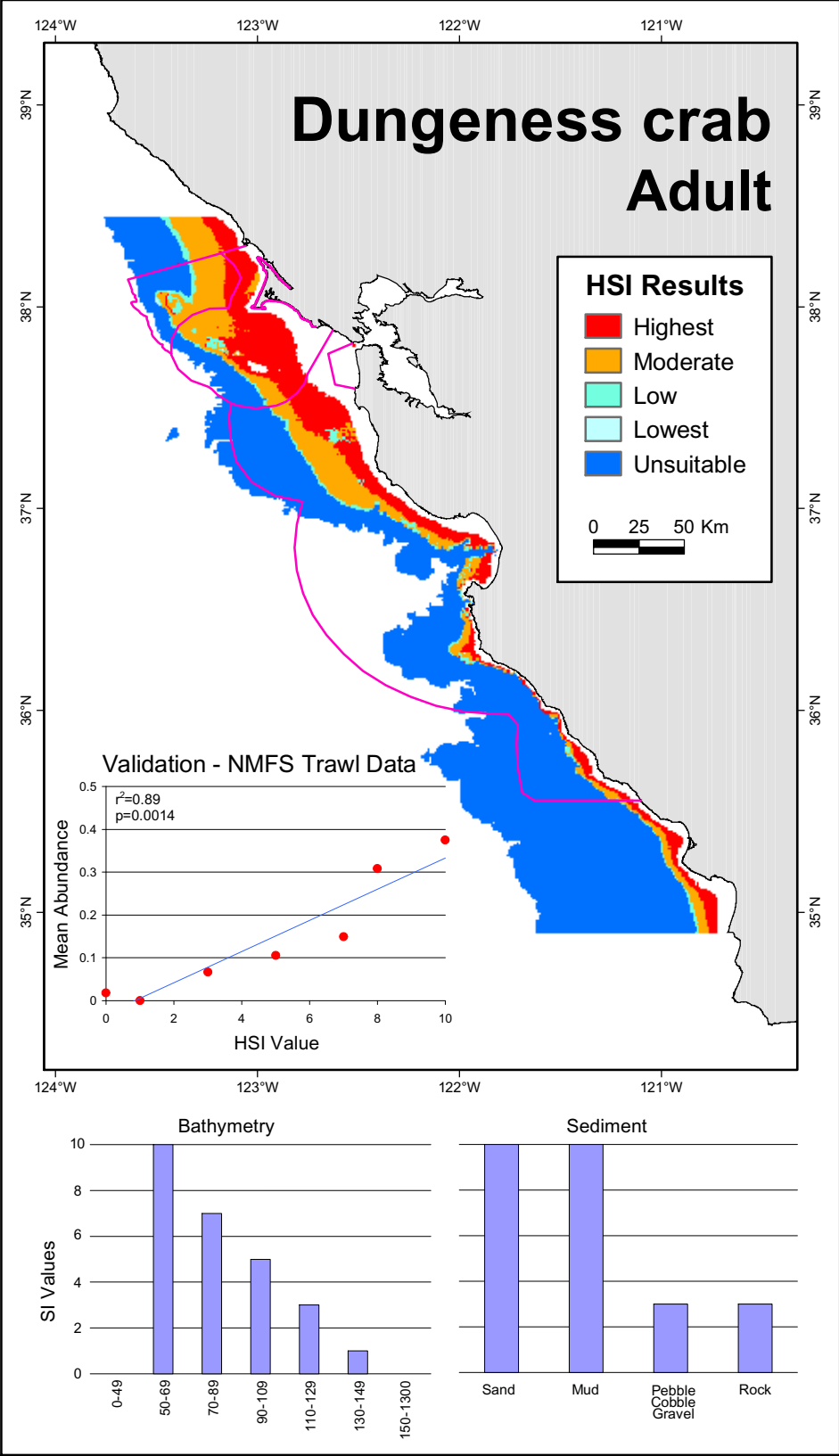


Figure 36. Potential distribution of habitat suitability for adult dungeness crab. Map inset contains validation statistics. SI values for bathymetry and substrate are graphically displayed below the map.

ABOUT THIS MAP

This map displays HSI model results for adult Dungeness crab during June-November (Figure 36). The map displays the potential distribution based on affinities to bathymetry and substrate. Predicted HSI values range from 10 (highest) to 0 (unsuitable) and were grouped into five classes: highest suitability (10-8), moderate (7-5), low (4-2), lowest (1), and unsuitable (0). SI values for bathymetry and substrate type are shown in the graphics below the mapped HSI results. Model performance graphics and statistical details are displayed in the map insets.

DATA SOURCES

Bathymetry SI: Wilkins et al., 1998 and Lauth, 2001.
Substrate SI: Pauley et al., 1989; Emmett et al., 1991; Leet et al., 2001; and CDFG, 2002.
Validation: Wilkins et al., 1998 and Turk et al., 2001.

METHODS

Bathymetry SI values for adult Dungeness crab were developed using the regression fitting technique. Substrate SI values were developed through literature review.

RESULTS AND DISCUSSION

Only adults were modeled within the study area because size information was lacking for crabs in the NMFS trawl data and scientific literature was not detailed enough to develop SI values for subadults. Dungeness crabs are an estuarine dependent species (Pauley et al., 1989), with adults exhibiting a shallow distribution (to 90 m) in coastal marine waters. Depth SI values derived from NMFS trawls confirmed this trend by exhibiting high SI values within 50-90 m. Suitability is probably high in the shallower near-shore environment (Emmett et al., 1991); however, trawl information was not available for this area. Literature sources described crab substrate preference to be soft sediments, with occasional utilization of rocky substrate. Habitat suitability based on these data resulted in a broad area of high suitability throughout the shallower waters of the Gulf of Farallones sanctuary (38% of available habitat), and much smaller proportions within Cordell (8.7%) and Monterey (10.4%) sanctuaries. Overall, this amounts to 2,809 km² of highly suitable habitat within the three sanctuaries. Moderate suitability, encompassing approximately 2,477.8 km², extends further offshore to approximately 130 m. The potential suitability of habitats rapidly declines to unsuitable beyond 130 m in depth. The model performed well with NMFS validation data and exhibited a strong positive correlation with predicted suitability values.



Gulf of the Farallones National Marine Sanctuary

Subsection 2.1.2: HABITAT SUITABILITY MODELING

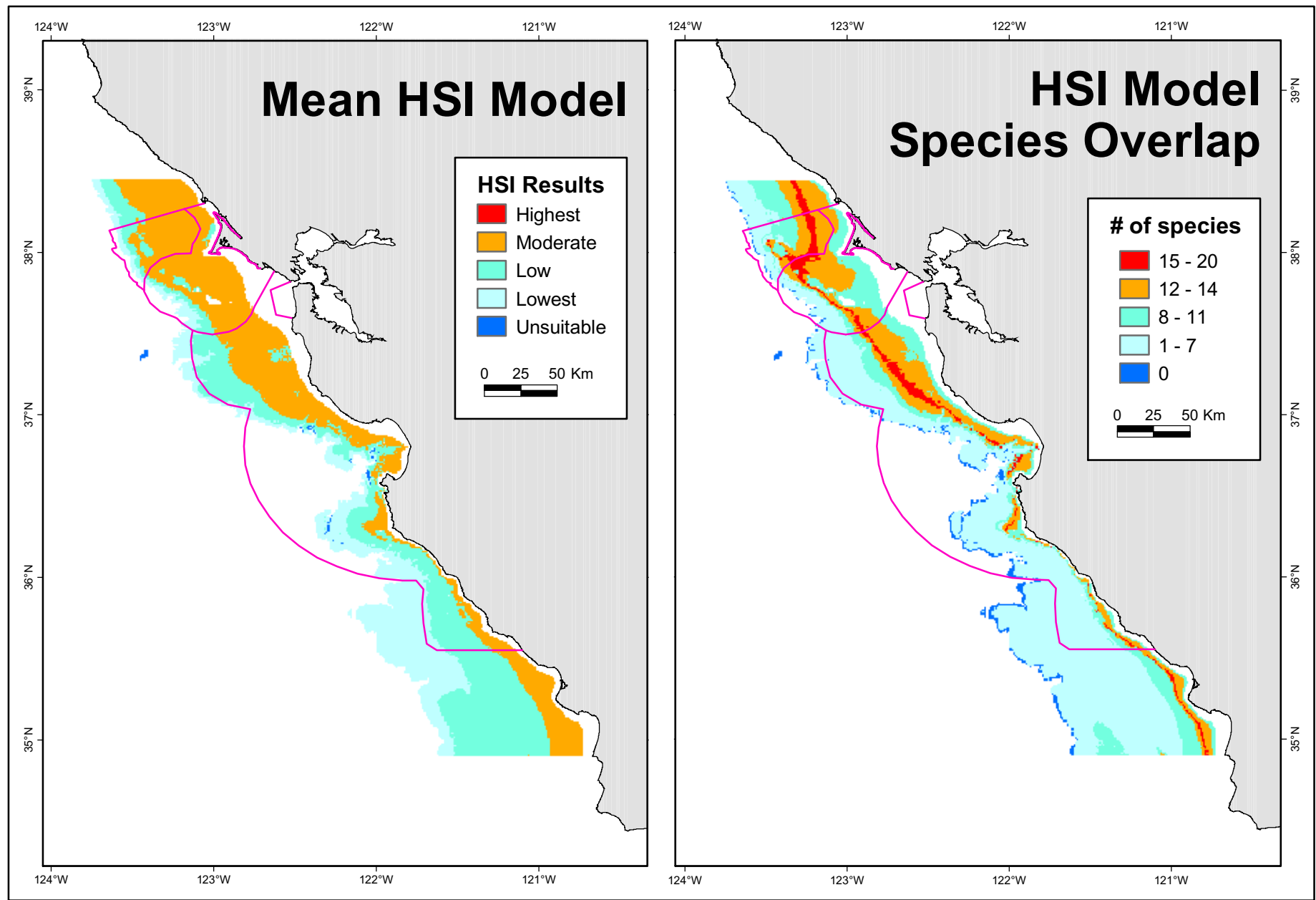


Figure 37. Areas of groundfish potential hot spots based on mean fish species HSI models and overlap of predicted highly suitable habitats.

ABOUT THESE MAPS

These maps display the results of two approaches that provide a synoptic view of overall habitat importance based on all the HSI models developed for the study area. Areas of potential habitat importance were first defined as an average view of habitat suitability across species and life stages. Secondly, individual maps of highly suitable habitats were overlain and areas or regions with the most overlap were considered important habitat or hot spots (Figure 37).

DATA SOURCES

See Individual HSI model results – CD-ROM.

METHODS

Mean HSI: HSI maps for all fish species and life stages were overlain and averaged by grid cell to evaluate overall suitability. Results were scaled in the same manner as individual HSI model results: Highest suitability (10-8), moderate (7-5), low (4-2), lowest (1) and unsuitable (0).

Cumulative Suitability: Frequency of occurrence of predicted HSI values for each fish and invertebrate species life stage were calculated and values greater than one standard deviation above the mean were chosen to represent highest suitability. New individual maps were created and grid cells were reclassified as highest suitability (1)

or other (0). All maps were overlain and summed to create a map of suitability overlap within the study area. These areas represent potential groundfish hot spots.

RESULTS AND DISCUSSION

The techniques described above are two possible approaches to estimate potential hot spots or areas of habitat importance. Composite maps displaying these areas were developed using all fish HSI model results to simulate the groundfish management strategy employed by NMFS, where all groundfish (83 species) are managed under one Fishery Management Plan. Mean HSI values across all 32 fish species and life stages yield no areas ranked as highly suitable (HSI values 10-8). Moderate suitability (7-5) occurs over the majority of the shelf region (to approximately 200 m) throughout the study area, most notably in the northern portion, where the shelf extends significantly farther offshore than in the southern portion. The majority of the area north of Monterey canyon consists of moderate suitability (to approximately 200 m), with low suitability extending through the deeper slope habitat. Smaller localized areas of low suitability exist within the shelf and represent areas of hard substrate. South of the Monterey canyon, low suitability comprises most of the study area, with a narrow zone of moderate suitability along the shallower shelf waters. Suitability drops from moderate to low just beyond the shelf edge throughout the study area.

Throughout the study area, maximum overlap of cumulative high suitability occurs on the shelf edge over soft sediments, which closely contour the 100 m isobath. Approximately half of the models overlap in this zone. The top two quintals encompass most of the shelf region and the zones of overlap are much broader in the northern portion of the study area compared to the southern.

These analyses reveal patterns of suitability related to depth and substrate. Highest suitability occurs on the continental shelf, over soft sediments, based on the two analytical approaches using the 33 HSI maps. These areas could be considered as habitats of importance that support fish abundance and diversity. Both methods portray highest suitability over the shelf that decline beyond the shelf edge. This pattern conforms to literature sources which state that the shelf, and more importantly the shelf break, are important areas for fish abundance and diversity (Yoklavich et al., 2000; Williams and Ralston, 2002). In addition, soft sediments are potentially more suitable than hard bottom throughout the study area. It is important to note that the results of these analyses are based on 19 species and are only a subset of the many groundfish species that occur within the study area. These results are clearly biased based on the species modeled and may not provide adequate representation of groundfish as a whole within the study area. Most of the species modeled have substrate affinities for soft sediments, and most exhibit depth preferences that fall within the shelf region. Ideally, many more models should be developed for additional species and analyzed to provide a more representative depiction of groundfish distribution within the study area.

Subsection 2.1.2: HABITAT SUITABILITY MODELING

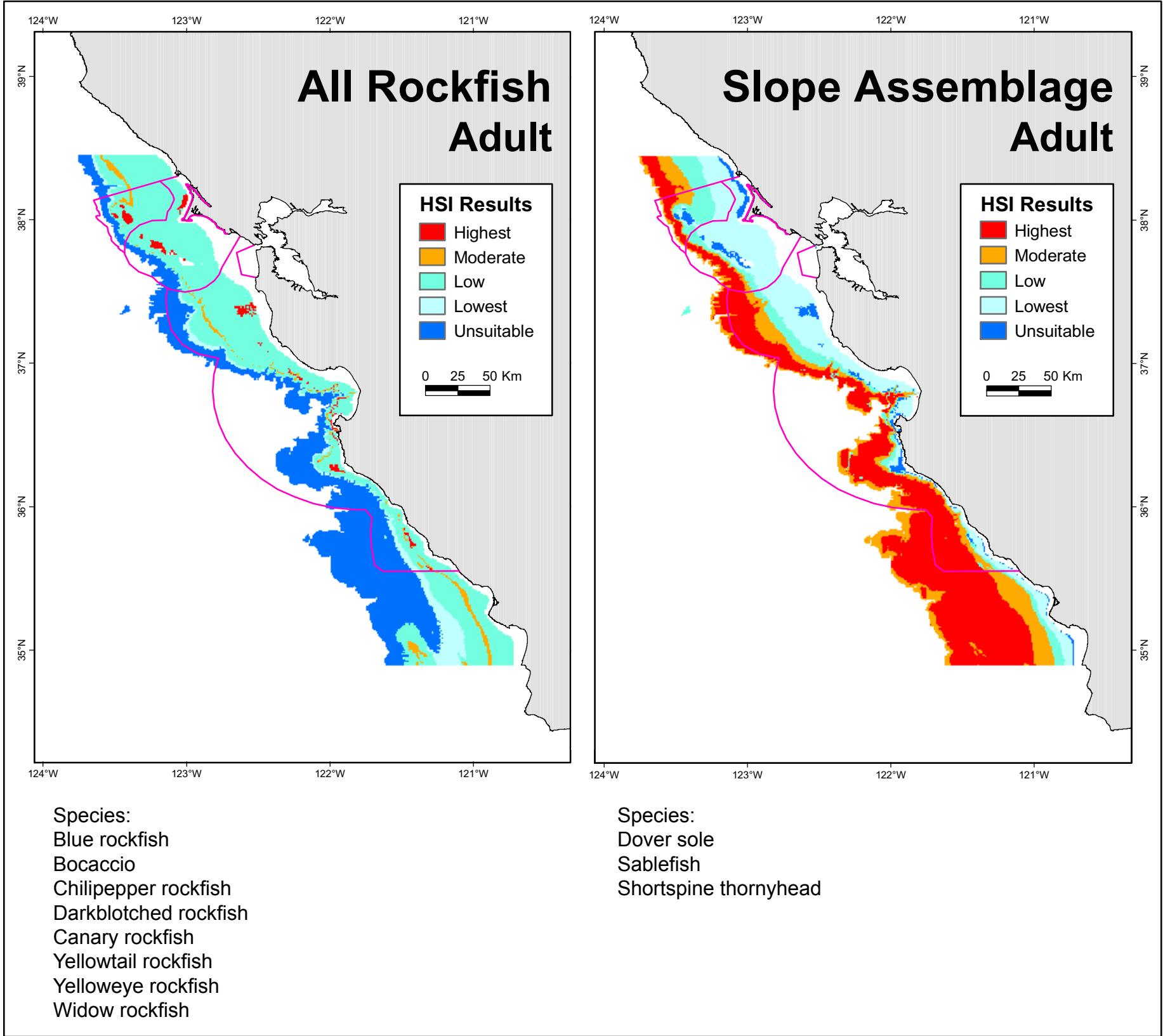


Figure 38. Areas of potential habitat importance based on mean HSI models for selected species assemblages.

ABOUT THESE MAPS

The maps provide one approach to assess habitat suitability based on HSI results for multiple species (Figure 38). HSI model results were averaged to assess the potential distribution of suitable habitats for 8 species of adult rockfish (left) and 3 adult slope species (right). Predicted HSI values range in scale from 10 (highest) to 0 (unsuitable). HSI results were grouped into five classes: highest suitability (10-8), moderate (7-5), low (4-2), lowest (1), and unsuitable (0).

DATA SOURCES

Adult rockfish map – HSI maps for adult bocaccio, chilipepper, darkblotched, canary, yellowtail, yelloweye, and widow rockfishes (CD-ROM).

Slope assemblage adults – HSI maps for adult Dover sole, sablefish, and shortspine thornyhead (CD-ROM).

METHODS

The slope assemblage was determined through cluster analysis of NMFS benthic slope trawl data (see Section 2.1.1 for methodology). All models for adult rockfish were combined to evaluate habitat suitability for these species as an assemblage. Both assemblages of fishes were analyzed by overlaying each individual HSI map and calculating the arithmetic mean across grid cells.

RESULTS AND DISCUSSION

Typically, management plans are not based on single species, but rather groups of species that exhibit similar life histories (Williams and Ralston, 2002). Estimating potential distributions for species assemblages from HSI models could be a valuable tool for resource managers to aid in the development of fishery management plans and conservation strategies. This approach provides a spatial view of important habitats for a given assemblage and generates a baseline set of data which can be used for a variety of management needs.

Individual HSI results for the 8 species of rockfishes displayed similar patterns of habitat suitability within the study area and, not surprisingly, the map of mean habitat suitability for these species is nearly identical to the individual maps. Hard substrates (pebble, cobble, gravel, rocky) within the shelf region promote highest suitability areas for these species. Moderate suitability was predicted for areas with mixed mud/rock substrate and mud areas in waters with depths between 200-450 m. These areas are emphasized based on HSI results from darkblotched rockfish, which exhibited strong affinity for hard and soft substrates, rather than only rocky substrate preference exhibited by the other rockfish species. Also, darkblotched rockfish distribution occurs in deeper waters compared to the other species of rockfish and may necessitate their omission from this assemblage. Regardless, suitable habitat for this group of species is limited, based on the distribution of rocky substrate within the study area. Overall, highly suitable habitat comprises 364 km² within the three sanctuary boundaries or 2% of the available habitat. Moderate suitability comprises even less area, 247 km², or 1.3% of available habitat.

Cluster analysis of NMFS trawl data revealed many assemblages of species that tend to occur together (see Section 2.1.1). Dover sole, sablefish, and shortspine thornyhead were identified as members of a strong species assemblage that occurs over soft sediments in deep waters of the continental shelf and slope. Mean HSI calculations resulted in a broad range of highly suitable habitats throughout the study area. Overall, 23% (4,257 km²) of the available habitat within the sanctuaries was predicted to be highly suitable habitat for this assemblage. An additional 10% (1,907 km²) was predicted moderately suitable habitat. Because of its greater depths and larger area, Monterey Bay sanctuary contained significantly more highly suitable habitat (3,773 km²) than Cordell Bank (170 km²) and Gulf of the Farallones (312 km²) sanctuaries.

Subsection 2.1.2: HABITAT SUITABILITY MODELING

SECTION SUMMARY

HSI modeling and mapping were considered to be a component of the biogeographic assessment because this approach provides spatial species- and lifestage-specific information for the north/central California marine region. This approach is intended to serve as an analytical tool for resource managers that can address a variety of needs: 1) developing maps in poorly sampled areas, 2) evaluating impact scenarios, 3) identifying habitats or areas for conservation or protection, and 4) assessing impacts of environmental change. The approach used here is similar to previous efforts that mapped near-shore rockfish distributions (Wright et al., 2000). The maps displayed near-shore rockfish distributions in relation to latitude, and maximum and common bathymetric ranges, based on information from peer-reviewed literature. The products generated from this study expand on this approach by including an additional parameter (substrate type). Also, models were developed which predicted the potential spatial distribution (based on affinities for bathymetric ranges and substrate type) for a select group of groundfish species. The maps provide a unique spatial view of potential groundfish habitats within and outside central California sanctuary boundaries.

It is important to note that the model results previously described are not actual, but potential distributions based on species affinities to the environmental variables used in the models. Interpretation of these results should be conducted carefully due to the variety of limitations associated with the biological and environmental data. Both bathymetry and substrate-type maps were created from the most current information available; however, the scale of information may cause inaccuracies in the interpretation of the model results. The bathymetry map, created with 78 million data points, provides a high quality, high resolution image of depth throughout the study area. The digital substrate map is a probabilistic interpretation of imagery data that has yet to be field validated. Given its original resolution (1:250,000), the map may under or overestimate substrate distribution within the study area; however, localized areas have more accurate information. For example, predicted areas of potential high suitability were extremely limited for species that exhibit strong affinities for rock substrate (rockfish, lingcod). Generally, less than 1% of the study area was considered optimal habitat for these species and may underestimate actual habitat distribution. These results are reflective of the low percentage of rock substrate included in the substrate map, which could be a result of the scale in which the original data were collected. Nevertheless, the map provides the most comprehensive substrate inventory for this region and it is recommended that additional substrate information be collected to further refine the maps. Additional digital data are available (e.g. sea surface temperature, kelp

distribution), and others can be developed and incorporated into the model as needed.

Decision making processes are typically not addressed at the species level but rather at a multi-species assemblage level. Thirty-four HSI models were created for 18 fish and 2 macro-invertebrate species to support multi-species analyses or assessments. Several techniques were conducted to assess habitat quality within the entire study area. One result indicated that the most potentially suitable habitat occurred on the shelf over mud substrates within depths of 100-120 m. As previously mentioned, these results were biased based on the selection of species modeled; however, the technique provides one method to identify areas of potential high habitat quality. Additional analyses identified important habitats for select species assemblages. Habitat suitability models for an assemblage of rockfish were developed and indicated that rocky habitats located on the shelf were identified as potential hot spots for adults; whereas, mud and sand substrates on the shelf were delineated as potentially important habitats for subadult rockfish.

In conclusion, the HSI maps can be used in a broad range of assessments which require information on habitat distribution and suitability. Individual species maps can be used to identify areas of varying habitat suitability and can be used to assess sensitivity to environmental or anthropogenic impacts. Lastly, it is recommended to continue developing HSI models for remaining groundfish species, as those presented here are only a small subset of the available resources within the study area.

REVIEWS

Two reviews were completed for the fish assemblage and habitat suitability analyses. During May and June 2002 informal meetings were held in Monterey, San Francisco, and Seattle to receive feedback on the approach and verify from the scientists that collected the data that the analyses were valid. Formal review workshops were held in October, 2002 in San Francisco, Seattle, and Monterey Bay and hosted local scientists, fishermen, and National Marine Sanctuary Program staff. Review comments were either incorporated or addressed in this product. We appreciate all the reviewers' time and effort when providing us this important feedback.



Chris Gotschalk

REVIEWERS

Tara Anderson, University of California, Santa Cruz
Carol Bernthal, Olympic Coast National Marine Sanctuary Program
Tonya Builder, Northwest Fisheries Science Center, NMFS
Gregor Cailliet, Moss Landing Marine Laboratory
Mark Carr, University of California, Santa Cruz
Josh Churchman, Fisherman
Elizabeth Clarke, Northwest Fisheries Science Center, NMFS
Steve Copps, Northwest Region, NMFS
Brad Damitz, Monterey Bay National Marine Sanctuary Program
Kathey Fosmark, Alliance of Communities for Sustainable Fisheries
Jim Glock, Sustainable Fisheries Division, NMFS
Gary Greene, Moss Landing Marine Laboratory

Chris Harvey, Northwest Fisheries Science Center, NMFS
Ruth Howell, Gulf of the Farallones National Marine Sanctuary Program
Roxanne Jordan, Alliance of Communities for Sustainable Fisheries
Chad King, Monterey Bay National Marine Sanctuary Program
Howatt King, California Department of Fish and Game
Bob Lauth, Alaska Fisheries Science Center, NMFS
Phil Levin, Northwest Fisheries Science Center, NMFS
Steve Lonhart, Monterey Bay National Marine Sanctuary Program
David Lott, Monterey Bay National Marine Sanctuary Program
Huff McGonigal, Monterey Bay National Marine Sanctuary Program
Nazila Merati, Pacific Marine Environmental Laboratory, NOAA

Subsection 2.1.2: HABITAT SUITABILITY MODELING

Richard Methot, Northwest Fisheries Science Center, NMFS
Jim Nybakken, Moss Landing Marine Laboratory
John Pearse, University of California, Santa Cruz
Stephen Ralston, Southwest Fisheries Science Center, NMFS
Paul Reilly, California Department of Fish and Game
Dale Roberts, Cordell Bank National Marine Sanctuary Program
Teresa Turk, Northwest Fisheries Science Center, NMFS
Tiffany Vance, Alaska Fisheries Science Center, NMFS
Mark Wilkins, Alaska Fisheries Science Center, NMFS
Deb Wilson-Vandenberg, California Department of Fish and Game
Lisa Wooninck, Southwest Fisheries Science Center, NMFS
Nancy Wright, California Department of Fish and Game
Levon Yengoyan, TerraLogic GIS
Mary Yoklavich, Southwest Fisheries Science Center, NMFS
Mark Zimmermann, Alaska Fisheries Science Center, NMFS

REFERENCES

Allen, M.J., and G.B. Smith. 1988. Atlas and zoogeography of common fishes in the Bering Sea and Northeastern Pacific. NOAA Tech. Rep. NMFS 66. Seattle, WA. 151 pp.

Brown, S.K., K.R. Buja, S.H. Jury, M.E. Monaco, and A. Banner. 2000. Habitat suitability models for eight fish and invertebrate species in Casco and Sheepscot Bays, Maine. N. Am. J. Fish. Manag., Vol. 20, pp. 408-435.

Cailliet, G.M., E.J. Burton, J.M. Cope, L.A. Kerr, R.J. Larson, D. VenTresca, R.N. Lea, and E. Knaggs. 2000. Final Report – Biological characteristics of near-shore fishes of California: A review of existing knowledge and proposed additional studies. Submitted to Pacific States Marine Fisheries Commission.

Cass, A.J., R.J. Beamish, and G.A. McFarlane. 1990. Lingcod (*Ophiodon elongatus*). Can. Spec. Pub. Fish. Aquat. Sci., Vol. 109, 40 pp.

Coyne, M.S. and J.D. Christensen. 1997. Habitat Suitability Index Modeling: Technical Guidelines. NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD. 19 pp.

Dark, T.A., and M.E. Wilkins. 1994. Distribution, abundance, and biological characteristics of groundfish off the coast of Washington, Oregon, and California, 1977-1986. NOAA Tech. Memo. NMFS 117. Seattle, WA. 114 pp.

Dark, T.A., M.E. Wilkins, and K. Edwards. 1983. Bottom Trawl Survey of Canary Rockfish (*Sebastes pinniger*), Yellowtail Rockfish (*S. flavidus*), Bocaccio (*S. paucispinis*) and Chilipepper (*S. goodei*) off Washington—California, 1980. NOAA Tech. Memo. F/NWC, Seattle, WA. 48 pp.

Emmett, R.L., S.L. Stone, S.A. Hinton, and M.E. Monaco. 1991. Distribution and abundance of fishes and invertebrates in West Coast estuaries, Volume II: Species life history summaries. ELMR Rep. No. 8. NOAA/NOS SEA Division, Rockville, MD. 329 pp.

Eschmeyer, W.N., E.S. Herald, H. Hammann, and K.P. Smith. 1983. A field guide to Pacific Coast Fishes. Houghton Mifflin Company, Boston, MA. 89 pp.

Feder, H.M., C.H. Turner, and C. Limbaugh. 1974. Observations on fishes associated with kelp beds in southern California. Cal. Dept. Fish and Game, Fish. Bull. Vol. 160, pp. 2-135.

Fishbase. 2002. Species summaries (online). <http://www.fishbase.org>.

Fitch, J.E., and R.J. Lavenberg. 1971. Marine Food and Game Fishes of California. California Natural History Guides, Vol. 28. Berkeley: Univ. California Press, Berkeley, CA. 98 pp.

Gauch, H.G., Jr. 1982. Multivariate analysis in community ecology. Cambridge Univ. Press, New York, NY. 145 pp.

Lassuy, D.R. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) – English sole. USFWS - Biol. Rep., Vol. 82(11.101), U.S. Army Corps Eng. TR EL-82-4. 17 pp.

Lauth, R.R. 2001. The 2000 Pacific West Coast Upper Continental Slope trawl survey of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, and length composition. NOAA Tech. Memo. NMFS-AFSC-120. Seattle, WA. 284 pp.

Leet, W.S., C.M. DeWees, and C.W. Haugen. 1992. California's Living Marine Resources: A Status Report. California Dept. Fish and Game. Sacramento, CA. 247 pp.

Leet, W.S., C.M. DeWees, R. Klingbeil, and E.J. Larson. 2001. California's Living Marine Resources: A Status Report. California Dept. Fish and Game. Sacramento, CA. 592 pp.

Love, M. 1996. Probably More Than You Want to Know About the Fishes of the Pacific Coast. Really Big Press, Santa Barbara, CA. 45 pp.

Love, M.S., L. Thorsteinson, C.W. Mecklenburg, and T.A. Mecklenberg. 1996. A checklist of marine and estuarine fishes of the Northeast Pacific, from Alaska to Baja California. National Biological Service. <http://id-www.ucsb.edu/lovelab/home.html> University of California, Santa Barbara, CA. 24 pp.

Love, M.S., P. Morris, M. McCrae, and R. Collins. 1990. Life History Aspects of 19 Rockfish Species (Scorpaenidae: *Sebastes*) from the Southern California Bight. NOAA Tech. Memo. NMFS 87. Seattle, WA. 113 pp.

Mahon, R., S.K. Brown, K.C.T. Zwanenburg, D. Atkinson, K.R. Buja, L. Claflin, G.D. Howell, M.E. Monaco, R.N. O'Boyle, and M. Sinclair. 1998. Assemblage and biogeography of demersal fishes of the east coast of North America. Can. J. Fish. Aquat. Sci., Vol. 55: pp. 1704-1738.

Miller, D.J., and R.N. Lea. 1972. Guide to the Coastal Marine Fishes of California. Cal. Dept. Fish and Game, Fish Bull. Vol. 157, pp. 23-29.

NOAA/NMFS. 1998. Essential Fish Habitat – West Coast Groundfish Appendix (online). <http://www.nwr.noaa.gov/1sustfsh/efhappendix>. NOAA/NMFS, EFH Core Team for West Coast Groundfish, Seattle, WA.

NOAA/NOS. 1990. West Coast of North America strategic assessment: Data atlas. Invertebrate and fish volume. Pre-publication edition. Strategic Assessment Branch, NOAA/NOS, Rockville, MD. 112 pp.

Phillips, J.B. 1964. Life history studies on ten species of rockfish (genus *Sebastes*). Cal. Dept. Fish and Game, Fish Bull., Vol. 126, p. 70.

Rubec, P.J., J.C. Bexley, H. Norris, M.S. Coyne, M.E. Monaco, S.G. Smith, and J.S. Ault. 1999. Suitability modeling to delineate habitat essential to sustainable fisheries. Am. Fish. Soc. Symp., Vol. 22: pp. 108-133.

Shaw, W.N., and T.J. Hassler. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) – Lingcod. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.119), U.S. Army Corps Eng. TR EL-82-4, 10 p.

Starr, R.M. 1998. Design principles for rockfish reserves on the U. S. West Coast. Marine harvest refugia for West Coast rockfish: A workshop., Pacific Grove, California.

U.S. Department of Commerce. Magnuson-Stevens Act Provisions. Federal Register: January 11, 2002 (Vol. 67, No. 8). Washington, DC: U.S. Govt. Printing Office. p. 1582.

USFWS. 1980a. Habitat as a basis for environmental assessment. Report ESM 101. U.S. Fish Wildl. Serv., Washington, DC.

USFWS. 1980b. Habitat evaluation procedures (HEP). Report ESM 102. U.S. Fish Wildl. Serv., Washington, DC.

USFWS. 1981. Standards for the development of habitat suitability index models for use with the habitat evaluation procedures. Report ESM 103. U.S. Fish Wildl. Serv., Washington, DC.

Wilkins, M.E., M. Zimmermann, and K.L. Weinberg. 1998. The 1995 Pacific West Coast Bottom Trawl Survey of Groundfish Resources: Estimates of Distribution, Abundance, and Length and Age Composition. NOAA Tech. Memo NMFS-AFSC-89.

Williams, E.H., and S. Ralston. In press. Distribution and co-occurrence of rockfishes (family Scorpaenidae) over trawlable shelf and slope habitats of California and Southern Oregon. Fishery Bulletin 000:000-000.

Wolotira, R.J., T.M. Sample, S.F. Noel, and C.R. Iten. 1993. Geographic and bathymetric distributions for many commercially important fishes and shellfishes off the West Coast of North America, based on research survey and commercial catch data, 1912-84. NOAA Tech. Memo. NMFS-AFSC-6. 184 p.

Wright, N., J. Kum, C. King, E. Knaggs, B. Leos, and C. Perez. 2000. Marine fishery profiles. Volume 1: Nearshore-Version 1. California Department of Fish and Game, Marine Region. 150 pp.

Yoklavich, M.M., H.G. Greene, G.M. Cailliet, D.E. Sullivan, R.N. Lea, and M.S. Love. 2000. Habitat associations of deep-water rockfishes in a submarine canyon: an example of a natural refuge. Fish Bulletin, U.S. 98:625-641.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS



INTRODUCTION

The California Current system runs south through the north/central California study area; it is one of the most productive ocean systems in the world (Glantz and Thompson, 1981). Hence, the study area contains a rich fauna of marine birds, as evidenced in species abundance and richness. In addition to a populous breeding community, the community of seasonal residents and migrants is even more robust, as central California is the destination for many marine bird species seeking productive feeding areas and acceptable habitat in which to spend their non-breeding periods. Unlike many marine organisms, marine birds have a tremendous mobility and the fact that many seek this region to find food bespeaks the region's trophic richness. Fortunately for the purpose of management of the central California National Marine Sanctuaries, the marine avifauna of the study area have been one of the most thoroughly surveyed.

DATA AND ANALYSES

Overview of Map Development and Analysis Process. The methods used in each survey were different, and because of this, careful consideration and correction are required to merge the data sets in a meaningful and scientifically acceptable way. The major steps of the data development for the bird analyses were as follows: species and study area selection; data set identification and collection; data corrections; data conversion into common comparable units; organizing the data into 5' latitude by 5' longitude cells; and calculating effort and density for each marine bird species. Seasonal density maps were then created for 40 species. Overall density, biomass density, and diversity maps were also created using distribution and abundance data for 76 bird species combined. These maps were reviewed at an expert workshop in October 2002. The draft bird report was also sent out for expert review in November (see list of reviewers at end of this section). Revisions were made to the maps and text based on that review.

Species Selected for Analysis. Selection criteria for bird species included in this assessment were: 1) the species must have a mostly marine distribution in the study area; and 2) adequate ocean survey data for the species is available and in a useable format. Species that are abundant, endangered, threatened, or a state species of concern were also a priority. The study area for the GIS assessment was seaward of the beach and did not include estuaries, so few shorebirds and waterfowl were included. Because marine distributions of birds are affected by where they breed and roost, we included information on the location and size of breeding and roosting sites, where available.

Table 11. Marine bird species used in this analysis.

Common Name	Scientific Name	Order/Family/SubFamily
Species that were mapped separately and used in the summary bird diversity and density analyses (n=31)		
Pacific Loon	<i>Gavia pacifica</i>	Gaviiformes/Gaviidae
Laysan Albatross	<i>Phoebastria immutabilis</i>	Procellariiformes/Diomedelidae
Black-footed Albatross	<i>Phoebastria nigripes</i>	Procellariiformes/Diomedelidae
Northern Fulmar	<i>Fulmarus glacialis</i>	Procellariiformes/Procellariidae
Pink-footed Shearwater	<i>Puffinus creatopus</i>	Procellariiformes/Procellariidae
Buller's Shearwater	<i>Puffinus bulleri</i>	Procellariiformes/Procellariidae
Sooty Shearwater	<i>Puffinus griseus</i>	Procellariiformes/Procellariidae
Black-vented Shearwater	<i>Puffinus opisthomelas</i>	Procellariiformes/Procellariidae
Fork-tailed Storm-petrel	<i>Oceanodroma furcata</i>	Procellariiformes/Hydrobatidae
Leach's Storm-petrel	<i>Oceanodroma leucorhoa</i>	Procellariiformes/Hydrobatidae
Ashy Storm-petrel	<i>Oceanodroma homochroa</i>	Procellariiformes/Hydrobatidae
Black Storm-petrel	<i>Oceanodroma melania</i>	Procellariiformes/Hydrobatidae
Brown Pelican	<i>Pelecanus occidentalis</i>	Pelecaniformes/Pelecanidae
Brandt's Cormorant	<i>Phalacrocorax penicillatus</i>	Pelecaniformes/Phalacrocoracidae
Double-crested Cormorant	<i>Phalacrocorax auritus</i>	Pelecaniformes/Phalacrocoracidae
Pelagic Cormorant	<i>Phalacrocorax pelagicus</i>	Pelecaniformes/Phalacrocoracidae
Red-necked Phalarope	<i>Phalaropus lobatus</i>	Charadriiformes/Scolopacidae
Red Phalarope	<i>Phalaropus fulicarius</i>	Charadriiformes/Scolopacidae
Heermann's Gull	<i>Larus heermanni</i>	Charadriiformes/Laridae/Larinae
Western Gull	<i>Larus occidentalis</i>	Charadriiformes/Laridae/Larinae
Glaucous-winged Gull	<i>Larus glaucescens</i>	Charadriiformes/Laridae/Larinae
Sabine's Gull	<i>Xema sabini</i>	Charadriiformes/Laridae/Larinae
California Gull	<i>Larus californicus</i>	Charadriiformes/Laridae/Larinae
Black-legged Kittiwake	<i>Rissa tridactyla</i>	Charadriiformes/Laridae/Larinae
Arctic Tern	<i>Sterna paradisaea</i>	Charadriiformes/Laridae/Sterninae
Common Murre	<i>Uria aalge</i>	Charadriiformes/Alcidae
Pigeon Guillemot	<i>Cepphus columba</i>	Charadriiformes/Alcidae
Marbled Murrelet	<i>Brachyramphus marmoratus</i>	Charadriiformes/Alcidae
Cassin's Auklet	<i>Ptychoramphus aleuticus</i>	Charadriiformes/Alcidae
Rhinoceros Auklet	<i>Cerorhinca monocerata</i>	Charadriiformes/Alcidae
Tufted Puffin	<i>Fratercula cirrhata</i>	Charadriiformes/Alcidae
Species mapped with related species & used in the summary diversity and density analyses (n=9, 4 maps)		
Western Grebe	<i>Aechmophorus occidentalis</i>	Podicipediformes/Podicipedidae
Clark's Grebe	<i>Aechmophorus clarkii</i>	Podicipediformes/Podicipedidae
Black Scoter	<i>Melanitta nigra</i>	Anseriformes/Anatidae
Surf Scoter	<i>Melanitta perspicillata</i>	Anseriformes/Anatidae
White-winged Scoter	<i>Melanitta fusca</i>	Anseriformes/Anatidae
Caspian Tern	<i>Sterna caspia</i>	Charadriiformes/Laridae/Sterninae
Elegant Tern	<i>Sterna elegans</i>	Charadriiformes/Laridae/Sterninae
Xantus's Murrelet	<i>Synthliboramphus hypoleucus</i>	Charadriiformes/Alcidae
Craveri's Murrelet	<i>Synthliboramphus craveri</i>	Charadriiformes/Alcidae
Species in the data set used only in the summary bird diversity and density analyses (n=37)		
Red-throated Loon	<i>Gavia stellata</i>	Gaviiformes/Gaviidae
Common Loon	<i>Gavia immer</i>	Gaviiformes/Gaviidae
Horned Grebe	<i>Podiceps auritus</i>	Podicipediformes/Podicipedidae
Red-necked Grebe	<i>Podiceps grisegena</i>	Podicipediformes/Podicipedidae
Eared Grebe	<i>Podiceps nigricollis</i>	Podicipediformes/Podicipedidae
Murphy's Petrel	<i>Pterodroma ultima</i>	Procellariiformes/Procellariidae
Cook's Petrel	<i>Pterodroma cookii</i>	Procellariiformes/Procellariidae
Parkinson's Petrel	<i>Procellaria parkinsoni</i>	Procellariiformes/Procellariidae
Flesh-footed Shearwater	<i>Puffinus carneipes</i>	Procellariiformes/Procellariidae
Short-tailed Shearwater	<i>Puffinus tenuirostris</i>	Procellariiformes/Procellariidae
Manx Shearwater	<i>Puffinus puffinus</i>	Procellariiformes/Procellariidae
Townsend's Shearwater	<i>Puffinus auricularis</i>	Procellariiformes/Procellariidae
Wilson's Storm-petrel	<i>Oceanites oceanicus</i>	Procellariiformes/Hydrobatidae
Wedge-rumped Storm-petrel	<i>Oceanodroma tethys</i>	Procellariiformes/Hydrobatidae
Markham's Storm-petrel	<i>Oceanodroma markhami</i>	Procellariiformes/Hydrobatidae
Least Storm-petrel	<i>Oceanodroma microsoma</i>	Procellariiformes/Hydrobatidae
Red-billed Tropicbird	<i>Phaethon aethereus</i>	Pelecaniformes/Phaethonidae
Brown Booby	<i>Sula leucogaster</i>	Pelecaniformes/Phaethonidae
White Pelican	<i>Pelecanus erythrorhynchos</i>	Pelecaniformes/Pelecanidae
South Polar Skua	<i>Stercorarius maccormicki</i>	Charadriiformes/Laridae/Stercorariinae
Pomarine Jaeger	<i>Stercorarius pomarinus</i>	Charadriiformes/Laridae/Stercorariinae

Table 11 cont. Marine bird species used in this analysis.

Common Name	Scientific Name	Order/Family/SubFamily
Species in the data set used only in the summary bird diversity and density analyses (n=37)		
Parasitic Jaeger	<i>Stercorarius parasiticus</i>	Charadriiformes/Laridae/Stercorariinae
Long-tailed Jaeger	<i>Stercorarius longicaudus</i>	Charadriiformes/Laridae/Stercorariinae
Bonaparte's Gull	<i>Larus philadelphia</i>	Charadriiformes/Laridae/Larinae
Mew Gull	<i>Larus canus</i>	Charadriiformes/Laridae/Larinae
Ring-billed Gull	<i>Larus delawarensis</i>	Charadriiformes/Laridae/Larinae
California Gull	<i>Larus californicus</i>	Charadriiformes/Laridae/Larinae
Thayer's Gull	<i>Larus thayeri</i>	Charadriiformes/Laridae/Larinae
Glaucous Gull	<i>Larus hyperboreus</i>	Charadriiformes/Laridae/Larinae
Red-legged Kittiwake	<i>Rissa brevirostris</i>	Charadriiformes/Laridae/Larinae
Royal Tern	<i>Sterna maxima</i>	Charadriiformes/Laridae/Sterninae
Common Tern	<i>Sterna hirundo</i>	Charadriiformes/Laridae/Sterninae
Forster's Tern	<i>Sterna forsteri</i>	Charadriiformes/Laridae/Sterninae
Thick-billed Murre	<i>Uria lomvia</i>	Charadriiformes/Alcidae
Ancient Murrelet	<i>Synthliboramphus antiquus</i>	Charadriiformes/Alcidae
Parakeet Auklet	<i>Aethia psittacula</i>	Charadriiformes/Alcidae
Horned Puffin	<i>Fratercula corniculata</i>	Charadriiformes/Alcidae

Table 11 contains the marine bird species that were selected for this analysis; data for 40 species were either mapped separately, or together for small species groups that generally co-occur (e.g., scoters). Ten of these species maps are included in this section; the remaining maps are on the accompanying CD-ROM. The remaining 37 species that occurred in the study area and data set were used to develop summary marine bird maps on marine bird diversity and density.

About the Survey Data and Literature Used in this Assessment. The survey data used in this summary were not designed with sanctuary resource management in mind, but include the interests of individual researchers to study spatial and temporal patterns of marine birds, federal government efforts to assess potential biological impacts of oil development, and state government efforts to respond to oil spills, of which there have been several major ones in the study area.

The Literature. Several reports, resulting from these surveys, provided background information on the occurrence patterns of marine birds in the region. The general composition and distribution of the marine avifauna was described by Ainley (1976) and Briggs et al. (1983, 1987a, b). Ainley and DeSante (1980) and Pyle and Henderson (1991) provide a fine-scale look at species' seasonal presence and migratory periods, as viewed from the Farallon Islands; Ainley et al. (1995a, c), Veit et al. (1997) and Oedekoven et al. (2001) provide an interannual view of variability in spatial occurrence. The last four references, as well as Ainley et al. (1994), Spear and Ainley (1999) and Ainley and Divoky (2001), investigated long-term temporal trends in populations. Information on habitat preferences of marine birds and how these are affected by ocean climate variability are provided for selected species in Ainley and Boekelheide (1990), Oedekoven et al. (2001), and in a GIS analysis by Allen (1994). The food-web relationships of marine birds in this region are also remarkably well known (Balz and Morejohn 1977; Ainley and Sanger 1979; Briggs et al. 1984, Briggs and Chu 1987; Chu 1984; Ainley and Boekelheide 1990; Ainley et al. 1996a, b; and Sydeman et al. 1997); and the breeding biology, including interannual variability in productivity and relationship to food-web variation, is very well known (Ainley and Boekelheide 1990, Ainley et al. 1995b). See the end of this section for complete list of references used.

The Data Sets. See Table 12, a summary of data sets used in the analyses, and Figures 39 and 40, which show the spatial extent of the individual data sets used

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

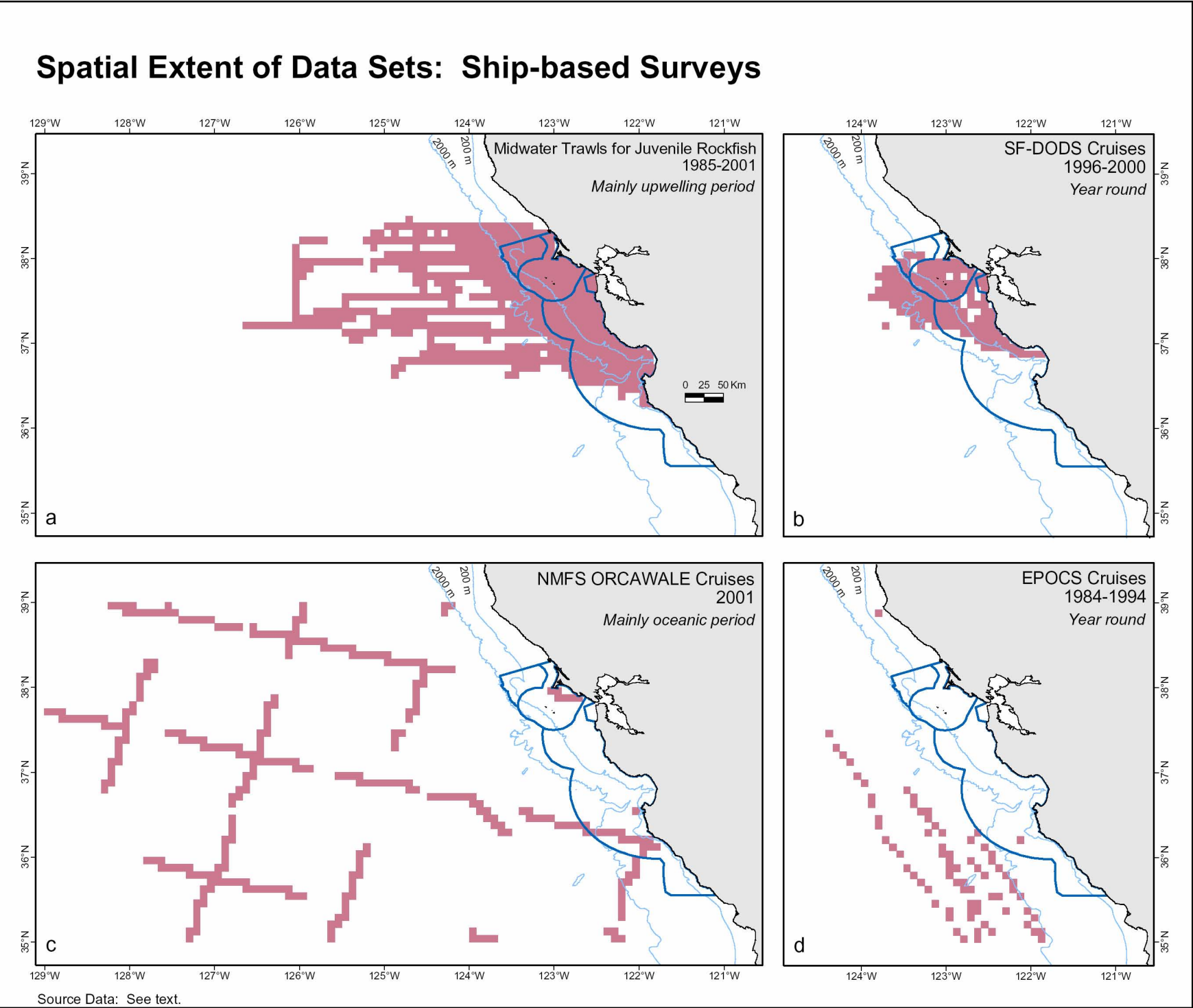


Figure 39. Spatial extent of data sets used in the marine bird analysis: ship-based surveys.

in the bird analyses. The ship and aerial strip transect data used in the GIS assessment were collected from 1980-2001 and occurred from Point Arena south to Point Sal, and offshore to the extent of data availability. However, the species maps do not generally include the full extent of available data, primarily because the assessment was focused on the national marine sanctuaries off central California. Also, estuaries were not part of the study area, but coastal colonies in estuaries were mapped to provide a more complete view of important areas for breeding species. See a more detailed description of data sets on the accompanying CD-ROM.

Data Synthesis.

Summarizing Transect Data into Grid Cells. The above data sets required a significant amount of processing and correction in order to synthesize them. Because wind speed affects detection of marine birds, data collected when wind speed exceeded 25 knots were excluded. Data were allocated into 5' latitude by 5' longitude cells. All aerial data were continuous; each ship-based data set was converted separately into a continuous transect format to the extent possible. The

Table 12. Summary of at-sea survey data sets used in the analyses.

Data Set	Principal Investigator	Platform Height	Habitat Covered2	Years	Ocean Seasons Sampled	Total Transect Width
MMS Low Altitude Aerial Surveys	Briggs	Pembroke, 62m	Surface survey of the shelf, slope & deep ocean beyond	1980-1983	All three seasons	50m
EPOCS Shipboard Surveys	Ainley	Surveyor, 12m, Discoverer, Oceanographer, 15m	Surface survey of the deep ocean	1984-1994	All three seasons	300-600m
CA Seabird Ecology Low-Altitude Aerial Surveys	Briggs	Partenavia, 62m	Surface survey of shelf and slope	1985	Mainly Upwelling	50m
NMFS Midwater Trawl Juv. Rockfish Assessment: Ship Surveys	Ainley	David Starr Jordan, 10m	Surface survey of shelf and slope to 3000 m	1985-2001	Mainly Upwelling	300m
OSPR Low Altitude Aerial Surveys	Bonnell, Tyler	Partenavia, 62m	Surface survey of shelf and slope	1994-1998, 2001	All three seasons	50m
MMS Santa Barbara Channel Low Altitude Aerial Surveys	Bonnell	Partenavia, 62m	Surface survey of shelf and slope	1995-1997	All three seasons	50m
SF-DODS Ship Surveys	Ainley	Point Sur, 8m	Surface survey of shelf and slope to 3000 m	1996-2000	All three seasons	300m
NMFS/SWFSC ORCAWALE Ship Survey	Ballance	MacArthur, 11m	Surface survey of the shelf, slope & deep ocean beyond	2001	Mainly Oceanic (Aug-Nov)	200-300m, depending on species & conditions

Note

See description of data sets on the CD for more information.

continuous aerial data were binned into the appropriate cell. For the SF-DODS and EPOCS studies, and the Rockfish Assessment cruises prior to 1997, the beginning position, ship heading, and speed were used to compute the end position of each 2-4 km continuous transect. From this, a midpoint of the transect was determined. As times of observations were not available, the position of the midpoint was used to select the cell to which the survey effort was assigned. If this midpoint fell on a cell boundary, it was assigned to the cell to the north or west. To maintain

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

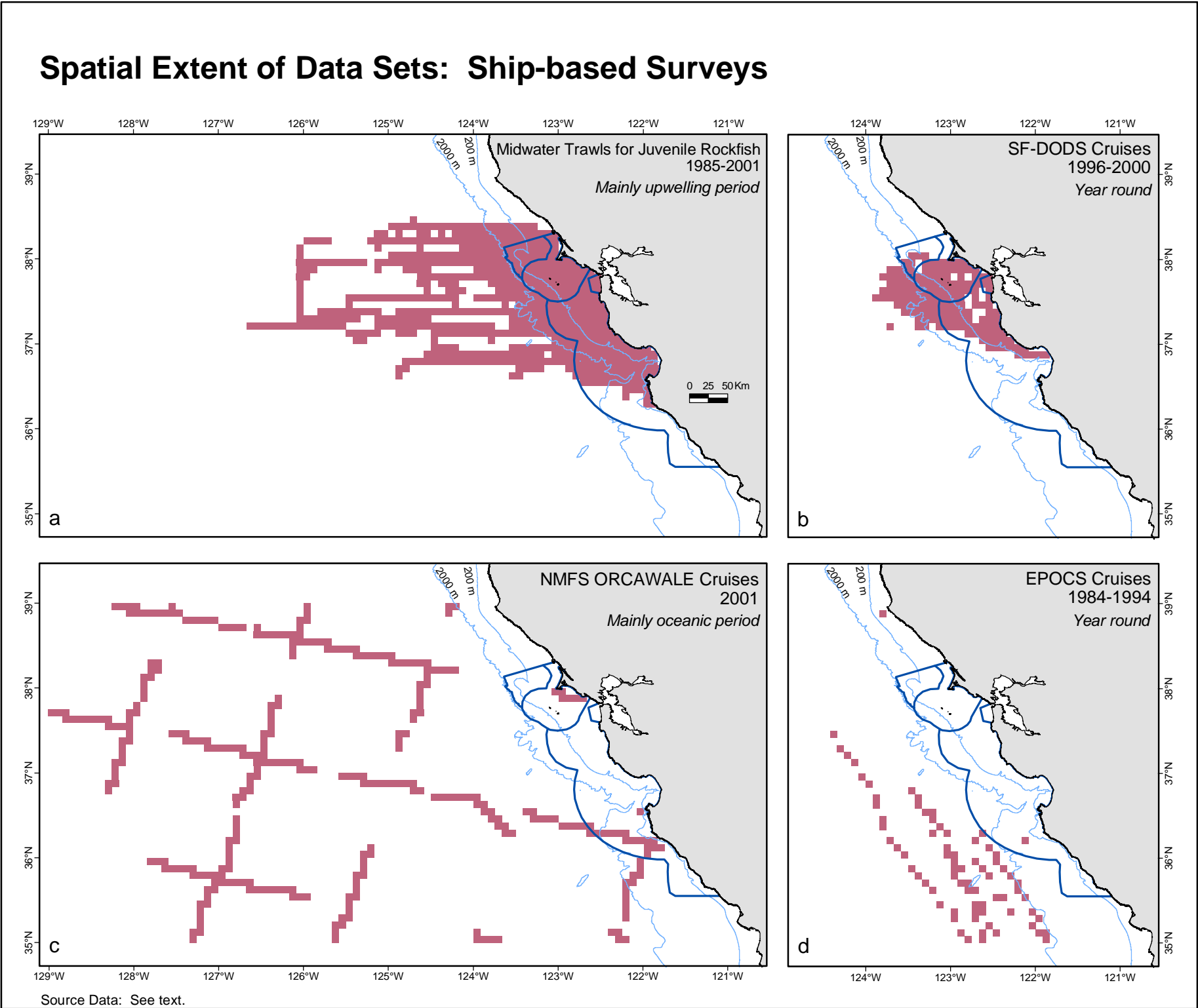


Figure 39. Spatial extent of data sets used in the marine bird analysis: ship-based surveys.

in the bird analyses. The ship and aerial strip transect data used in the GIS assessment were collected from 1980-2001 and occurred from Point Arena south to Point Sal, and offshore to the extent of data availability. However, the species maps do not generally include the full extent of available data, primarily because the assessment was focused on the national marine sanctuaries off central California. Also, estuaries were not part of the study area, but coastal colonies in estuaries were mapped to provide a more complete view of important areas for breeding species. See a more detailed description of data sets on the accompanying CD-ROM.

Data Synthesis.
Summarizing Transect Data into Grid Cells. The above data sets required a significant amount of processing and correction in order to synthesize them. Because wind speed affects detection of marine birds, data collected when wind speed exceeded 25 knots were excluded. Data were allocated into 5' latitude by 5' longitude cells. All aerial data were continuous; each ship-based data set was converted separately into a continuous transect format to the extent possible. The continuous aerial data were binned into the appropriate cell. For the SF-DODS and EPOCS

Table 12. Summary of at-sea survey data sets used in the analyses.

Data Set	Principal Investigator	Platform Height	Habitat Covered2	Years	Ocean Seasons Sampled	Total Transect Width
MMS Low Altitude Aerial Surveys	Briggs	Pembroke, 62m	Surface survey of the shelf, slope & deep ocean beyond	1980-1983	All three seasons	50m
EPOCS Shipboard Surveys	Ainley	Surveyor, 12m, Discoverer, Oceanographer, 15m	Surface survey of the deep ocean	1984-1994	All three seasons	300-600m
CA Seabird Ecology Low-Altitude Aerial Surveys	Briggs	Partenavia, 62m	Surface survey of shelf and slope	1985	Mainly Upwelling	50m
NMFS Midwater Trawl Juv. Rockfish Assessment: Ship Surveys	Ainley	David Starr Jordan, 10m	Surface survey of shelf and slope to 3000 m	1985-2001	Mainly Upwelling	300m
OSPR Low Altitude Aerial Surveys	Bonnell, Tyler	Partenavia, 62m	Surface survey of shelf and slope	1994-1998, 2001	All three seasons	50m
MMS Santa Barbara Channel Low Altitude Aerial Surveys	Bonnell	Partenavia, 62m	Surface survey of shelf and slope	1995-1997	All three seasons	50m
SF-DODS Ship Surveys	Ainley	Point Sur, 8m	Surface survey of shelf and slope to 3000 m	1996-2000	All three seasons	300m
NMFS/SWFSC ORCAWALE Ship Survey	Ballance	MacArthur, 11m	Surface survey of the shelf, slope & deep ocean beyond	2001	Mainly Oceanic (Aug-Nov)	200-300m, depending on species & conditions

Note
See description of data sets on the CD for more information on the data sets.

studies, and the Rockfish Assessment cruises prior to 1997, the beginning position, ship heading, and speed were used to compute the end position of each 2-4 km continuous transect. From this, a midpoint of the transect was determined. As times of observations were not available, the position of the midpoint was used to select the cell to which the survey effort was assigned. If this midpoint fell on a cell boundary, it was assigned to the cell to the north or west. To maintain

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

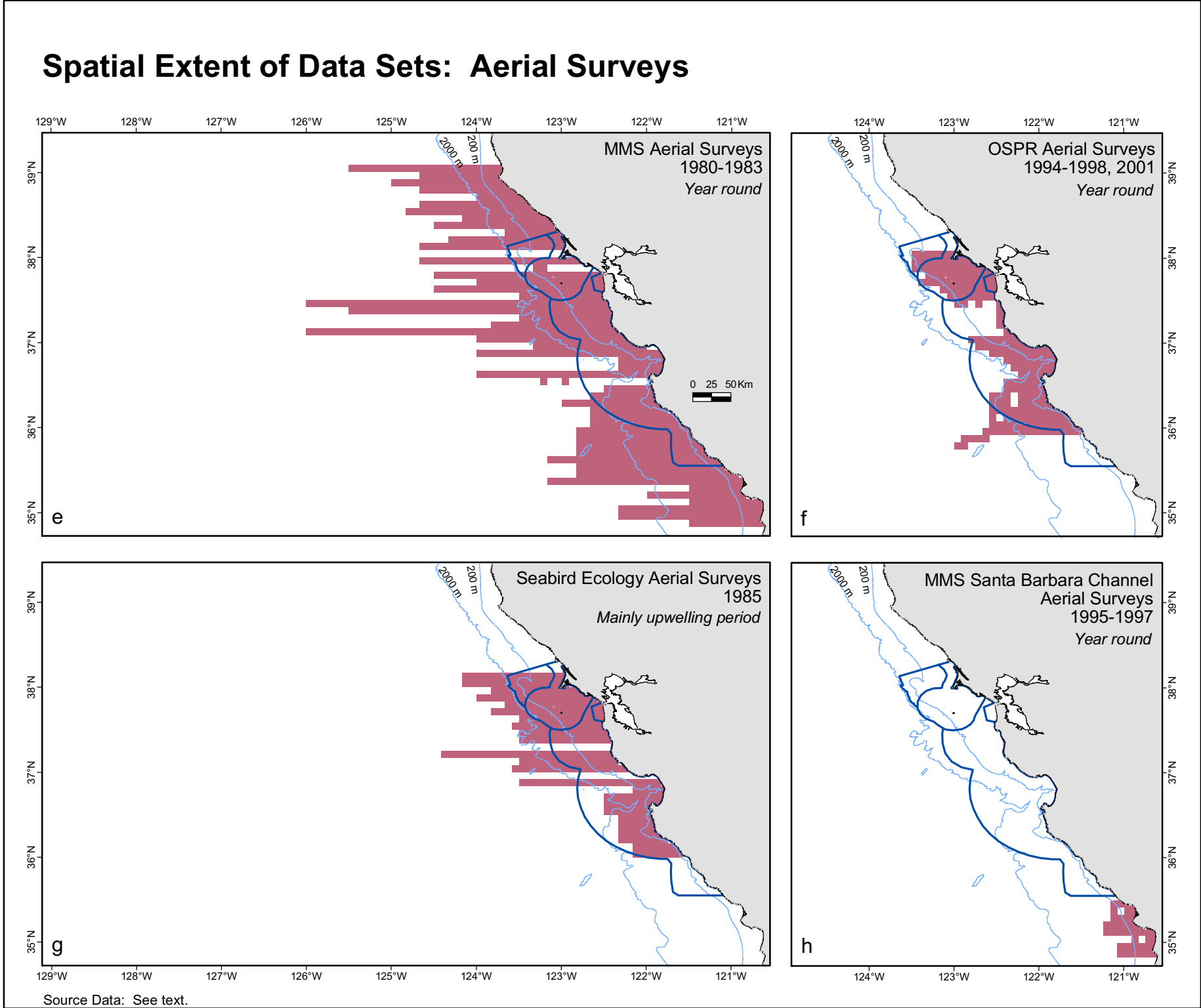


Figure 40. Spatial extent of data sets used in the analysis: aerial surveys.

Table 13. Summary of combined data set effort by ocean season.

Ocean Season	Dates Used for Each Ocean Season	Number of Months	Years Included	Kilometers of Trackline Surveyed	Number of Visits	Number of 5' Cells Sampled
Upwelling	15 Mar-14 Aug	5	1980-1982, 1985-2001	64177	11050	1335
Oceanic	15 Aug-14 Nov	3	1980-1982, 1991, 1994-2001	29263	4171	1130
Davidson Current	15 Nov-14 Mar	4	1980-1986, 1991-2001	40265	5878	1593
TOTAL	1 Jan – 31 Dec	12	1980-2001	133705	21099	2294

Note. The total number of cells sampled is not a straight sum; it refers to the number of unique cells surveyed.

the correspondence between effort and bird observations, observations were also assigned to the transect midpoints. For the Rockfish Assessment Cruises from 1997 onward, effort was assigned to the cells through which the vessel passed based on the proportion of trackline that fell within each cell, and observations were interpolated along the cruise track according to the time of each observation. The marine bird survey data from the ORCAWALE cruise were recorded continuously using automatic recording software and were processed like the aerial survey data.

Data Analysis.

Effort. The combined at-sea survey effort for birds included 133,705 kilometers of trackline, as well as 128,886 observations of 973,318 birds in the analyzed data set. Survey effort by ocean season is summarized in Figure 41 and Table 13.

Calculating Density. From the digitized survey data, we mapped the distribution of effort and of species observations into a grid of 5-minute latitude by 5-minute longitude cells, using MMS-CDAS (Marine Mammal and Seabird Computer Database Analysis System, MMS 2001). The species data were first transformed into densities on the basis of strip widths (which varied by platform, depending on speed and height above water; see Table 12). The number of birds of each species seen was then divided by area surveyed to estimate density in each cell for that data set. For construction of density plots, if a cell was censused in other years or the same year by another survey, densities in cells were averaged and weighted according to effort.

Organizing Data into Ocean Seasons. Effort and species data were organized and mapped into three distinct ocean seasons (Bolin and Abbott 1963): Upwelling, Oceanic, and Davidson Current, because ocean conditions differ distinctly among them and are known to affect the biota of the California Current (e.g. Ainley 1976, Briggs et al. 1987). As there is significant interannual variation in the actual initiation and termination of these seasons, the following dates were defined for each season for purposes of analysis: Upwelling Season is 15 March-14 August; Oceanic Season is 15 August-14 November; and Davidson Current Season is 15 November-14 March.

Seasonal Density Maps for Individual Species. Seasonal density maps were generated for 40 bird species. These maps were then reviewed to characterize the spatial and seasonal occurrence pattern of each species in the study area.

Seasonal High Use Areas for Individual Species. In order to provide a summary map of space use, seasonal density data were binned into 10-minute latitude by 10-minute longitude cells for each species or species group. The purpose of the seasonal high use maps is to provide

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

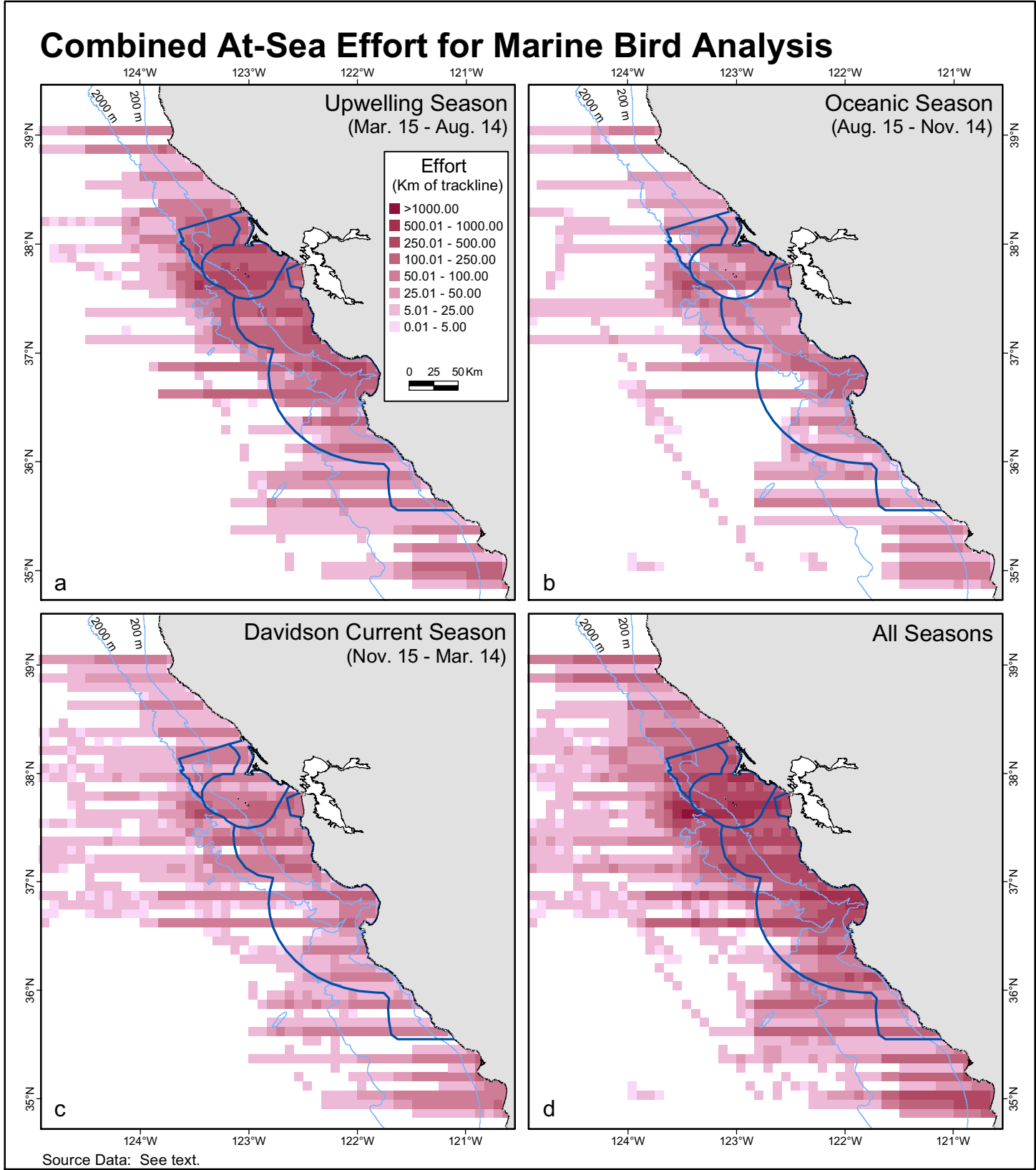


Figure 41. Total survey effort for marine bird analyses.

one overall map for each species (or group of species) that describes the spatial and temporal use patterns, as clearly as possible. The seasonal high use index is based on the top 20% of sampled cells within a given season. The index is therefore sensitive to cells which were not sampled in any one of the three seasons, causing a downward bias in the index.

Use of a 10-minute block size greatly reduces the magnitude of this bias. Non-zero cells were then ranked and those in the top 20 percent were selected and defined as seasonal high use areas. Cells were then mapped with colors corresponding to the number of seasons of high use. Cells in which there was effort but birds were not observed, and cells where sightings occurred but were never high use areas, were also mapped with two additional colors.

Major Breeding Colonies. Best available breeding colony data (number of breeding birds, mostly from Carter, et al. 1992, with some updates) were mapped for each species for which colony information was available, on the same map as the "seasonal high use" information. A map (pp. 81) and table (p. 53) of the top 40 breeding colonies is included in Section 2.2; the complete colony table, based on best available data, will be included on the CD-ROM.

Spatial and Temporal Patterns Summary Table. Density maps for 44 species were inspected to identify which cells exhibited the highest density each season. Using the two highest density categories for each species, relatively high density areas associated with large bathymetric areas (inner shelf, outer shelf, upper slope) were identified, as well as with several smaller discrete habitat features (e.g., Monterey Bay Canyon) (p. 51).

Summary of Overall Density, Biomass and Diversity Maps for 76 Marine Bird Species. Overall marine bird densities were mapped for each season and for all seasons combined. Densities of all species in a cell were converted to biomass by multiplying density for each species by its average body mass (from Dunning 1993), then summing for all species detected in that cell. Biomass was then mapped in a fashion similar to the individual species' density maps.

The Shannon Index (Shannon and Weaver 1949)

$$H' = - \sum_{i=1}^S \left[\left(\frac{n_i}{n} \right) \ln \left(\frac{n_i}{n} \right) \right]$$

was used to quantify species diversity. This index measures the degree to which the species assemblage is dominated by a single species. If species A dominates all the species seen within a cell, then diversity is low, and vice versa. Diversity was calculated for each season and all seasons combined. To

standardize for variable effort among cells and variable strip width for species, density was used for each species in each cell as the basis for calculating the diversity index value.

The Shannon Index was selected as the diversity metric because it is widely used and accepted in community ecology. It has three desirable properties for a diversity index, noted below. Most diversity indices do not take these three qualities into account. For more information on diversity indices, see Ecological Diversity, E.C. Pielou, pp 7-18.

1. The diversity index is greatest when all species in the community are equally represented in numbers (e.g., evenness in a community). Or, for a given number of species (e.g., richness value), the diversity index should have it's greatest value when the proportion of each species is the same.
2. Given two completely diverse or even communities, the one with the higher number of species has a greater diversity value.
3. The last property is difficult to summarize: This property takes into account the hierarchical nature, or "representativeness" in the biological classification of each species when estimating diversity.

Evaluating Variation in Species Abundance. In order to evaluate factors that affect the abundance of marine birds in the study area, a regression model was developed (Seber 1977, Kleinbaum et al. 1988), with marine bird density as the dependent variable. Independent variables that could be addressed in the limited time frame included: ocean season, year, ocean depth, distance to nearest breeding colony, distance to shelf break (estimated to the 200 meter isobath), distance to deep ocean (estimated to the 2000 meter isobath), latitude, periods of short-term ocean climate anomalies (e.g., El Niño or La Niña events), and latitude. The data used for the multiple regression analyses was a subset of the mapping data set; the regression data set included cell-based density data from 1985 - 2002 (6,641 cell samples, all with effort ≥ 0.24km² per cell).

Response to Variation in Marine Climate. Short-term ocean climate anomaly in this report is often referred to as ENSO (El Niño/Southern Oscillation), and generally refers to the climatic events that cause significant interannual changes in thermocline depth and water temperature in the study area, resulting in warm-water periods (often known as El Niño events), cold-water periods (often known as La Niña events), or neutral periods, when the water is neither unusually warm nor cold (Ainley et al. 1995b and references therein).

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

The official ENSO events and time periods tracked by NOAA are relevant for regions to the far south and well outside of the study area; the official NOAA ENSO periods do not accurately reflect the timing of the ENSO-related periods that occur off central California. In part, this is because the marine climate of the central and northern California Current region is affected as well by variation in atmospheric pressure centers in the Gulf of Alaska.

Table 14. Assignment of warm, cold and neutral periods, based on surface water temperatures off Cental California.

Year	Davidson Current Season	Upwelling Season	Oceanic Season
1975	Cold	Cold	Cold
1976	Cold	Cold	Warm
1977	Warm	Cold	Neutral
1978	Warm	Warm	Cold
1979	Cold	Neutral	Neutral
1980	Warm	Neutral	Cold
1981	Warm	Cold	Cold
1982	Neutral	Neutral	Neutral
1983	Warm	Warm	Warm
1984	Warm	Neutral	Neutral
1985	Cold	Warm	Cold
1986	Neutral	Neutral	Neutral
1987	Warm	Warm	Warm
1988	Neutral	Neutral	Cold
1989	Cold	Neutral	Neutral
1990	Cold	Cold	Neutral
1991	Cold	Cold	Neutral
1992	Warm	Warm	Warm
1993	Warm	Warm	Warm
1994	Warm	Neutral	Cold
1995	Neutral	Warm	Neutral
1996	Warm	Neutral	Cold
1997	Neutral	Neutral	Warm
1998	Warm	Warm	Cold
1999	Cold	Cold	Cold
2000	Cold	Cold	Cold
2001	Cold	Cold	-

To determine the time periods and effects of interannual climate anomalies of marine birds as evidenced in the study area (i.e., warm-water, cold-water and neutral periods), two sea-surface temperature data sets for central California were analyzed: daily temperatures taken as part of a Scripps Institution of Oceanography program at Southeast Farallon Island and the NOAA CoastWatch data off central California. Both data

sets ranged from 1975-2001. Table 14 indicates the periods of unusual weather (warm water, cold water, and neutral) as determined from these data.

Also affecting marine climate are decadal-scale factors involved in the Pacific Decadal Oscillation (Mantua and Hare 2002). A regime shift occurred in 1976, from cold to warm, and may have occurred again in the winter of 1998/1999, from warm to cold. This means that the overall average state of the system could be characterized as warm or cold, with other shorter-term variation embedded (e.g., ENSO). The effect of regime shifts on marine bird occurrence is addressed near the end of this report.

ANALYTICAL MAP PRODUCTS

The analytical map products (Figures 42-60) include seasonal density maps for 13 species and nine summary analyses maps for marine birds. These maps are a subset of the total mapped results for this analysis. Additional maps and text products are included on the CD-ROM. Of the 35 species maps, these ten were chosen for inclusion in the document because they represent a variety of spatial and temporal patterns in and around the sanctuaries.



Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

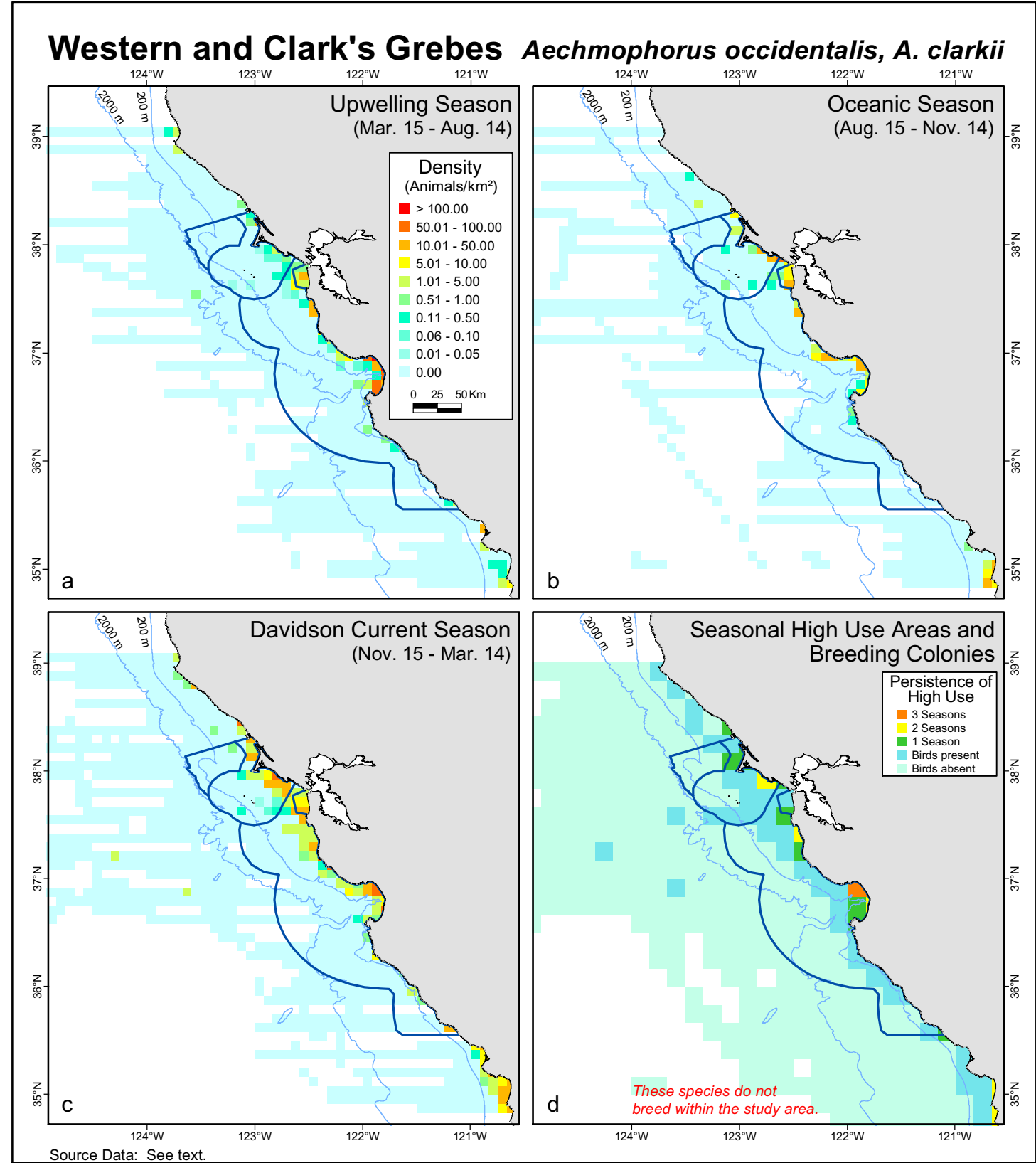


Figure 42. Western and Clark's grebes, seasonal density and high use areas.

ABOUT THESE MAPS

Figures 42a, b, and c show the density (birds/km²) of western and Clark's grebes (combined) in the Upwelling, Oceanic, and Davidson Current seasons, displayed in five minute latitude by five minute longitude cells. Densities are based on the combined data sets of several studies (see "Methods" and "Data Sources" below). The color and mapping intervals were customized to show the most structure and to highlight significant areas, while allowing comparisons among marine bird species. Cells that were surveyed but in which no grebes were observed have a density of zero. Areas not surveyed appear white; no information is available for these areas. Blue lines indicate the boundaries of the National Marine Sanctuaries in the study area: Cordell Bank, Gulf of the Farallones, and Monterey Bay.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence and abundance in the study area, map d shows seasonal high-use areas, displayed in 10 minute latitude by 10 minute longitude cells. The seasonal high use map provides a further synthesis of densities presented in maps a, b and c, and portrays the relative importance of various areas to the species. Areas with consistently high use are highlighted on this map. To provide a relative reference for the "high use" areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there), or present but at lesser concentrations in any particular season. See the "Methods" section below for further explanation of seasonal high-use areas.

DATA SOURCES

Densities for marine birds at sea are based on data from eight survey programs conducted between 1980 and 2001, which were combined into a new MMS-CDAS data set (MMS, 2001) using software (CDAS) developed for the Minerals Management Service. Of the data sets on the original MMS-CDAS CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program is ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis (see section overview for details on individual data sets).

Data sources for aerial, at-sea data include MMS-CDAS (MMS 2001), and California Department of Fish and Game, Office of Spill Prevention and Response (CDF&G-OSPR, unpublished data). Early data were collected using methods described by Briggs et al. (1983, 1987b); more recent data were collected using updated technology but using the same general method. Data sources for ship-based survey data include: David Ainley of H. T. Harvey and Associates and Carol Keiper of Oikonos (unpublished data; see Oedekoven et al., 2001 for details on survey methods); and Lisa T. Ballance, from the Ecology Pro-

gram of the Southwest Fisheries Science Center, NMFS, NOAA (unpublished data).

Although the at-sea data span the years from 1980 to 2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991, and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources" below). Bird observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of birds of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was surveyed more than once, densities were averaged, with an adjustment made for effort.

The seasonal high-use areas on map d were developed using a similar approach as for Maps a, b and c, but the data were binned into 10' x 10' cells. For each season, the cells with densities in the top 20% of non-zero values were designated "high use" for that season. Cells were scored for "high use" in one, two, or three seasons and are depicted by color. To provide a relative reference for the "high use" areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season).

RESULTS AND DISCUSSION

Individuals of this closely-related species pair (separable by plumage, but sharing the same ecological niche) are abundant in the near-shore waters of the study area. Surveys tallied 2,511 sightings of 13,525 individuals. During most oil spills in this region, these species have been near the top of the list, by number, of oiled birds. These birds breed inland at freshwater lakes and marshes.

A multiple regression model of nine independent variables explained 15.5% of variation in cell density; most important vari-

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

ables were season, and an inverse relationship with distance to land and to depth; see Table 19. These results reflect the large number of grebes found in shallow waters (mean depth was 131 ± 37 m) within a few kilometers of shore (mean distance to land was 7.4 ± 1 km), and primarily during the Oceanic Season. Moderate numbers are present during the Upwelling and Davidson Current seasons. During the latter, these grebes expanded farther offshore to the middle continental shelf (mean depth of occurrence 260 ± 80 m).

Inshore waters of the Gulf of the Farallones (San Francisco Bay tidal plume), Monterey Bay, and Estero/San Luis Obispo bays had particularly high concentrations of these birds. North and south of marine sanctuary boundaries in the study area, these species were found only at isolated river mouths. Therefore, the sanctuary boundaries encompass the majority of the species habitat in the study area, except for the 'sanctuary exclusion area' off San Francisco and Pacifica, which contained many grebes. The broad continental shelf off central California is ideal for these grebes, which capture prey by diving; it is likely they are capable of exploiting most of the water column lying over the shelf, in spite of their inshore occurrence. Abundance of this species-pair remained stable between 1985 and 2002.

These grebes feed mainly on long-bodied, fusiform fish, such as herring and anchovy. See Tables 15 and 16 for related summary information.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

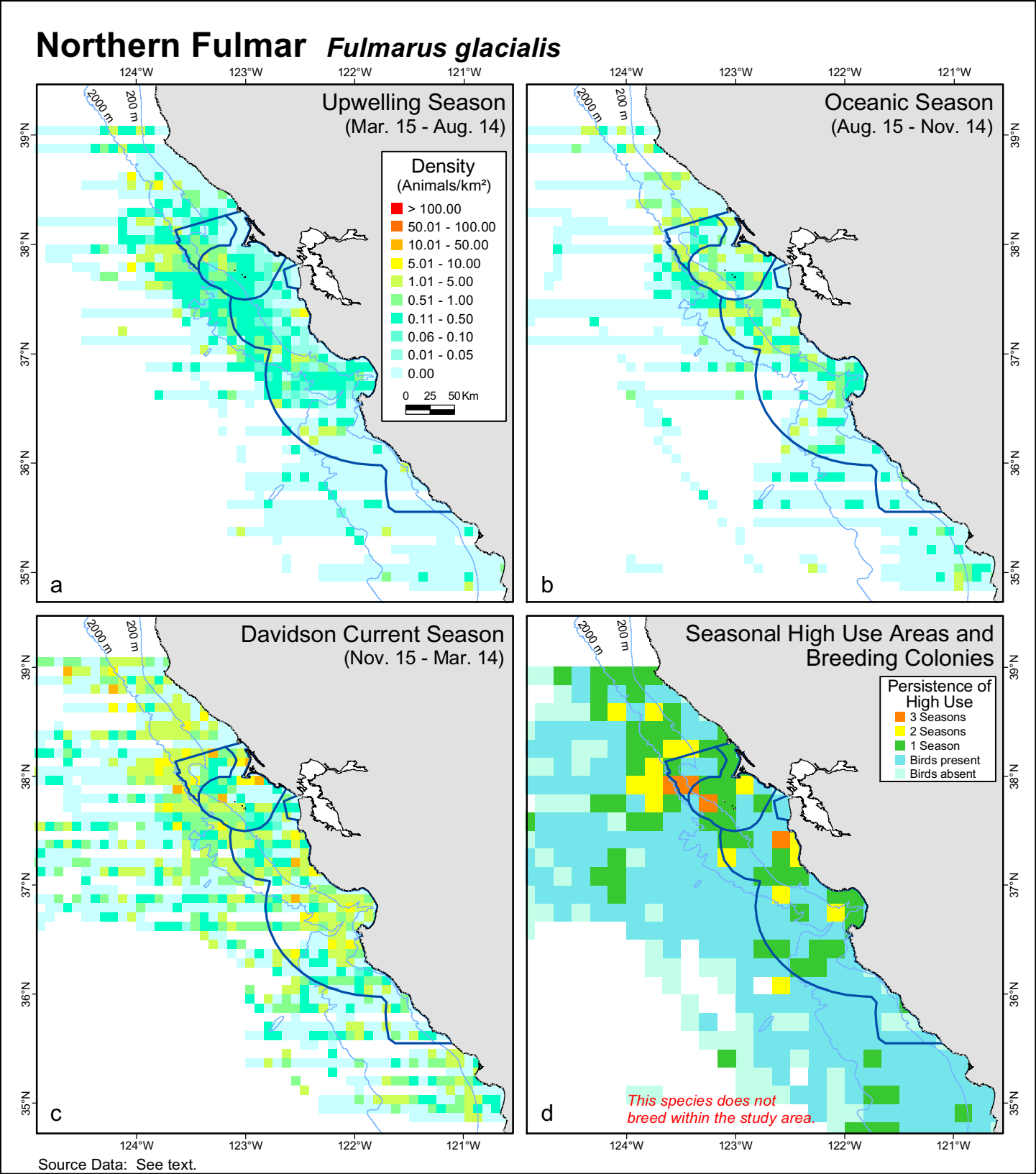


Figure 43. Northern fulmar, seasonal density and high use areas.

ABOUT THESE MAPS

Figures 43 a, b, and c show the density (birds/km²) of northern fulmar in the Upwelling, Oceanic, and Davidson Current seasons, displayed in five minute latitude by five minute longitude cells. Densities are based on the combined data sets of several studies (see “Methods” and “Data Sources” below). The color and mapping intervals were customized to show the most structure and to highlight significant areas, while allowing comparisons among marine bird species. Cells that were surveyed but in which no fulmars were observed have a density of zero. Areas not surveyed appear white; no information is available for these areas. Blue lines indicate the boundaries of the National Marine Sanctuaries in the study area: Cordell Bank, Gulf of the Farallones, and Monterey Bay.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence and abundance in the study area, map d shows seasonal high-use areas, displayed in 10 minute latitude by 10 minute longitude cells. The seasonal high use map provides a further synthesis of densities presented in Maps a, b and c, and portrays the relative importance of various areas to the species. Areas with consistently high use are highlighted on this map. To provide a relative reference for the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there), or present but at lesser concentrations in any particular season. See the “Methods” section below for further explanation of seasonal high-use areas.

Because the sighting data for this species extends beyond the western extent of the standard map frame shown here, additional maps were made that include a greater western extent. These maps (with the word “pelagic” in the filename) are included on the CDROM.

DATA SOURCES

Densities for marine birds at sea are based on data from eight survey programs conducted between 1980 and 2001, which were combined into a new MMS-CDAS data set (MMS, 2001) using software (CDAS) developed for the Minerals Management Service. Of the data sets on the original MMS-CDAS CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program is ongoing and data from recent years are added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis (see section overview for details on individual data sets).

Data sources for aerial, at-sea data include MMS-CDAS (2001), and California Department of Fish and Game, Office of Spill Prevention and Response (CDF&G-OSPR, unpublished

data). Early data were collected using methods described by Briggs et al. (1983, 1987b); more recent data were collected using updated technology but using the same general method. Data sources for ship-based survey data include: David Ainley of H. T. Harvey and Associates and Carol Keiper of Oikonos (unpublished data; see Oedekoven et al., 2001 for details on survey methods); and Lisa T. Ballance, from the Ecology Program of the Southwest Fisheries Science Center, NMFS, NOAA (unpublished data).

Although the at-sea data span the years from 1980 to 2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991, and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see “Data Sources” below). Bird observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of birds of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was surveyed more than once, densities were averaged, with an adjustment made for effort.

The seasonal high-use areas on map d were developed using a similar approach as for Maps a, b and c, but the data were binned into 10’ x 10’ cells. For each season, the cells with densities in the top 20% of non-zero values were designated “high use” for that season. Cells were scored for “high use” in one, two, or three seasons and are depicted by color. To provide a relative reference for the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season).

RESULTS AND DISCUSSION

Northern fulmar, which nests on islands in the Aleutian Island chain and Bering Sea, is common in waters of the continental slope as well as the outer waters of the continental shelf off

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

north/central California. Surveys recorded 4,486 sightings of 6,345 individuals. In some winters, fulmars were particularly abundant off this coast, such as in 1986, 1991, 1996, and 1999.

A multiple regression analysis of nine independent variables explained 21.3% of the variability of this species' cell density; important explanatory variables were season, ENSO period (periods of unusually warm or cold sea temperatures), and year; see Table 19. The species' occurrence is confined principally to the Davidson Current Season, especially prevalent during La Niña. For a subarctic species, surprisingly high densities are present during the Upwelling Season; many of these individuals exhibit heavy molt indicating that they might be juveniles.

Based on the data available, the species' population trajectory during the study period exhibited a curvilinear pattern: a slight decline between 1985 and 1989, followed by an increase from 1990 to 2002. Numbers rose particularly in the last few years, perhaps indicating a response to the shift in 1999 from a warm to a cold ocean regime (see subsection on response to climate change).

Like the albatrosses, this species is attracted to trawlers, where the species scavenges offal. Therefore, areas of concentration for northern fulmars during the study period were (and may still be) important areas of traditionally higher fishing activity such as Cordell Bank, Fanny Shoal, and nearby canyons. This pattern is better illustrated during the Upwelling Season, when the species is much less abundant. In the latter season, the species spreads far more widely, occurring farther offshore and over deeper depths. Although fulmars are widespread off central California, the boundaries of the National Marine Sanctuaries encompass an important area for this species.

Northern fulmars are generalists that feed on live and dead prey found at the surface. They are one of the few marine species that feed extensively on gelatinous zooplankton, e.g. jellyfish. See Tables 15 and 16 for related summary information.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

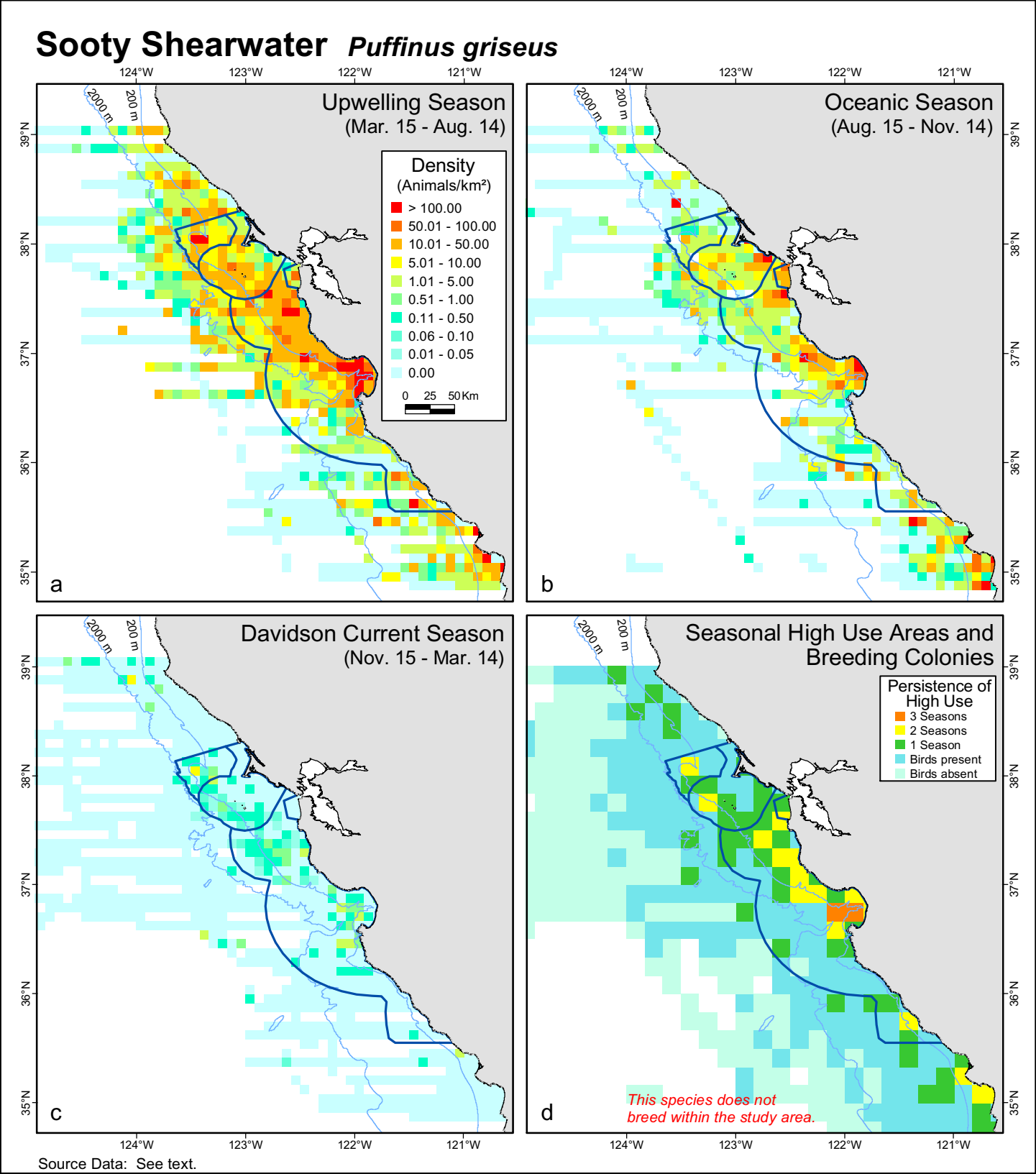


Figure 44. Sooty shearwater, seasonal density and high use areas.

ABOUT THESE MAPS

Figures 44a, b, and c show the density (birds/km²) of sooty shearwater in the Upwelling, Oceanic, and Davidson Current seasons, displayed in five minute latitude by five minute longitude cells. Densities are based on the combined data sets of several studies (see “Methods” and “Data Sources” below). The color and mapping intervals were customized to show the most structure and to highlight significant areas, while allowing comparisons among marine bird species. Cells that were surveyed but in which no sooty shearwaters were observed have a density of zero. Areas not surveyed appear white; no information is available for these areas. Blue lines indicate the boundaries of the National Marine Sanctuaries in the study area: Cordell Bank, Gulf of the Farallones, and Monterey Bay.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence and abundance in the study area, map d shows seasonal high-use areas, displayed in 10 minute latitude by 10 minute longitude cells. The seasonal high use map provides a further synthesis of densities presented in Maps a, b and c, and portrays the relative importance of various areas to the species. Areas with consistently high use are highlighted on this map. To provide a relative reference for the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there), or present but at lesser concentrations in any particular season. See the “Methods” section below for further explanation of seasonal high-use areas.

Because the sighting data for this species extends beyond the western extent of the standard map frame shown here, additional maps were made that include a greater western extent. These maps (with the word “pelagic” in the file name) are included on the CDROM.

DATA SOURCES

Densities for marine birds at sea are based on data from eight survey programs conducted between 1980 and 2001, which were combined into a new MMS-CDAS data set (MMS, 2001) using software (CDAS) developed for the Minerals Management Service. Of the data sets on the original MMS-CDAS CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program is ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis (see section overview for details on individual data sets).

Data sources for aerial, at-sea data include MMS-CDAS (MMS, 2001), and California Department of Fish and Game, Office of Spill Prevention and Response (CDF&G-OSPR, unpublished data). Early data were collected using methods described by Briggs et al. (1983, 1987b); more recent data were collected using updated technology but using the same general method. Data sources for ship-based survey data include: David Ainley of H. T. Harvey and Associates and Carol Keiper of Oikonos (unpublished data; see Oedekoven et al., 2001 for details on survey methods); and Lisa T. Ballance, from the Ecology Program of the Southwest Fisheries Science Center, NMFS, NOAA (unpublished data).

Although the at-sea data span the years from 1980 to 2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991, and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see “Data Sources” below). Bird observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of birds of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was surveyed more than once, densities were averaged, with an adjustment made for effort.

The seasonal high-use areas on map d were developed using a similar approach as for Maps a, b and c, but the data were binned into 10' x 10' cells. For each season, the cells with densities in the top 20% of non-zero values were designated “high use” for that season. Cells were scored for “high use” in one, two, or three seasons and are depicted by color. To provide a relative reference for the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season).

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

RESULTS AND DISCUSSION

Sooty shearwaters nest in the sub-Antarctic, particularly on island of Tierra del Fuego and New Zealand, and winters in the Peru and California current regions. During the Upwelling Season, the sooty shearwater is the most abundant marine bird off California, and this is the case, by far, for waters within the boundaries of the north/central California national marine sanctuaries. Surveys tallied 20,750 sightings of 323,176 individuals, indicating that the species usually occurs in large concentrations.

A multiple regression analysis of nine independent variables explained 43.3% of the variation in cell density, with season, an inverse relationship to year, and ENSO period (periods of unusually warm or cold sea temperatures) being the most important variables; see Table 19. These results further reflect the restriction of this species' occurrence off California largely to the Upwelling Season, and to greater abundance when ocean climate is unaffected by short-term climate anomaly. In other words, sooty shearwaters were less abundant in the study area during El Niño and La Niña. From a decadal perspective they declined over the years, although this effect was curvilinear: a slight increase between 1985 and 1991, a steep decline to 1998, and a moderate increase subsequently. Whether or not the latter increase is a response to the shift to a cold ocean regime in 1999 remains to be seen. The continental shelf and upper slope are the main habitats frequented by this species (mean ocean depth where sooty shearwaters occurred was $380 \pm 10\text{m}$).

The sooty shearwater was present in greatest densities in Monterey Bay. Throughout the California current (Veit et al, 1997), this species has declined severely in abundance during the recent warm regime (1976-1999), as noted above. Even now, though, it is still very abundant in Monterey Bay, probably because of the large anchovy source there. Other important areas (but not comparable to Monterey Bay), include Pioneer and Ascension canyons, Farallon Escarpment and Fanny Shoal, as well as the ocean area off Pacifica and Estero/San Luis Obispo bays. National marine sanctuary waters become even more important to this species during the Oceanic Season, as remnants of the population, just before their long southward migration, fatten on the oil-rich anchovies.

Sooty shearwaters feed on fish, squid, and invertebrates that they acquire by pursuit, plunging to a depth of 10-15 m. During the early Upwelling Season the main prey are euphausiids and squid, a diet that shifts more to oily fish, such as anchovy, in the late Upwelling Season. See Tables 15 and 16 for related summary information.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

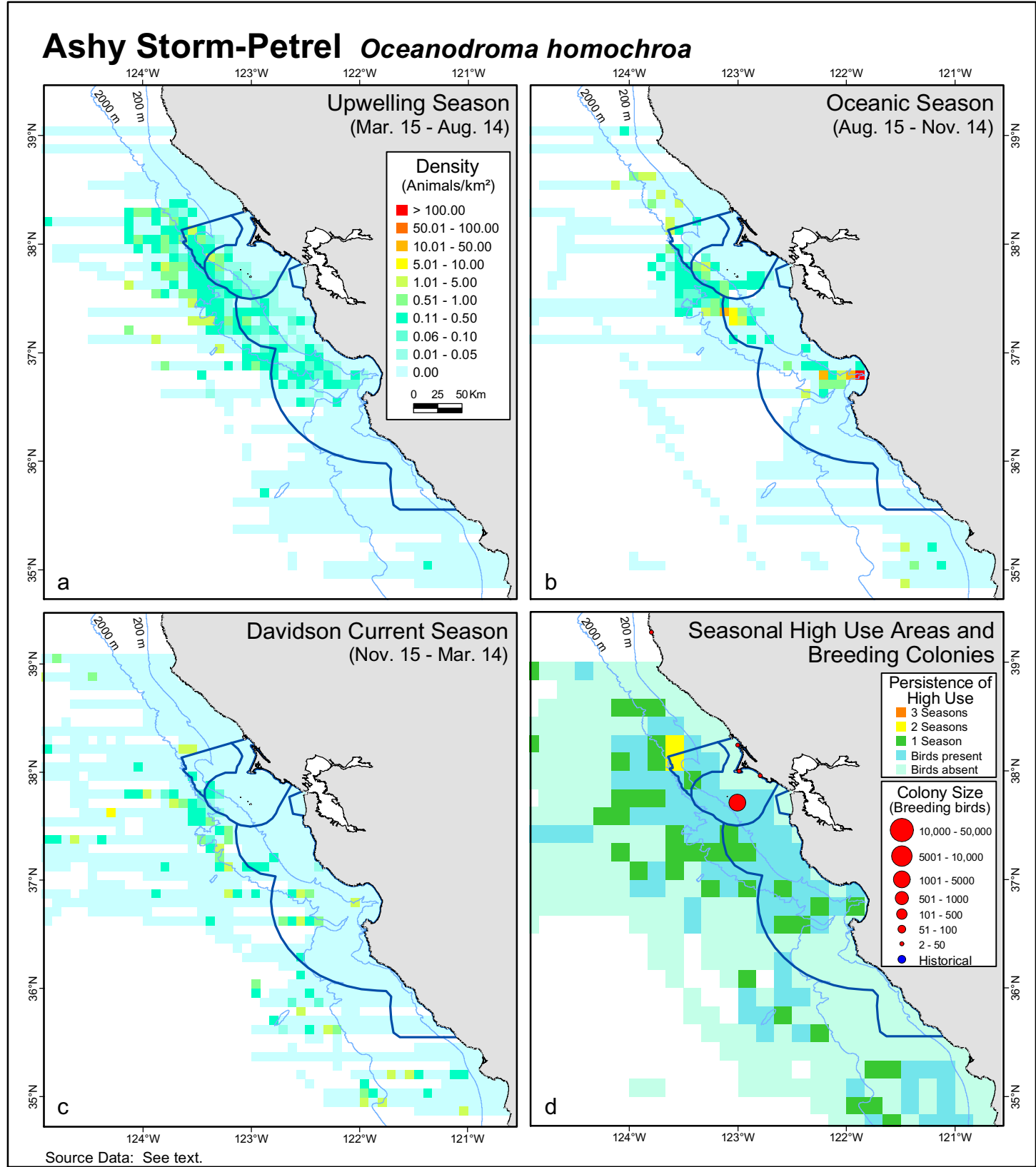


Figure 45. Ashy storm-petrel, seasonal density, high use areas, and breeding colonies.

ABOUT THESE MAPS

Figures 45a, b, and c show the density (birds/km²) of ashy storm-petrel in the Upwelling, Oceanic, and Davidson Current seasons, displayed in five minute latitude by five minute longitude cells. Densities are based on the combined data sets of several studies (see “Methods” and “Data Sources” below). The color and mapping intervals were customized to show the most structure and to highlight significant areas, while allowing comparisons among marine bird species. Cells that were surveyed but in which no ashy storm-petrels were observed have a density of zero. Areas not surveyed appear white; no information is available for these areas. Blue lines indicate the boundaries of the National Marine Sanctuaries in the study area: Cordell Bank, Gulf of the Farallones, and Monterey Bay.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence and abundance in the study area, map d shows seasonal high-use areas, displayed in 10 minute latitude by 10 minute longitude cells, and breeding colonies. The seasonal high use map provides a further synthesis of densities presented in Maps a, b and c, and portrays the relative importance of various areas to the species. Areas with consistently high use are highlighted on this map. To provide a relative reference for the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there), or present but at lesser concentrations in any particular season. See the “Methods” section below for further explanation of seasonal high-use areas. Breeding colonies are also shown; the relative size of the symbols indicates the colony size.

Because the sighting data for this species extends beyond the western extent of the standard map frame shown here, additional maps were made that include a greater western extent. These maps (with the word “pelagic” in the filename) are included on the CDROM.

DATA SOURCES

Densities for marine birds at sea are based on data from eight survey programs conducted between 1980 and 2001, which were combined into a new MMS-CDAS data set (MMS, 2001) using software (CDAS) developed for the Minerals Management Service. Of the data sets on the original MMS-CDAS CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program is ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis (see section overview for details on individual data sets).

Data sources for aerial, at-sea data include MMS-CDAS (MMS, 2001), California Department of Fish and Game, Office of Spill Prevention and Response (CDF&G-OSPR, unpublished data). Early data were collected using methods described by Briggs et al. (1983, 1987b); more recent data were collected using updated technology but using the same general method. Data sources for ship-based survey data include: David Ainley of H. T. Harvey and Associates and Carol Keiper of Oikonos (unpublished data; see Oedekoven et al., 2001 for details on survey methods); and Lisa T. Ballance, from the Ecology Program of the Southwest Fisheries Science Center, NMFS, NOAA (unpublished data). Data on ashy storm-petrel colonies were obtained from Carter et al. (1992) supplemented by Sydeman et al. (1998), Whitworth et al. (2002).

Although the at-sea data span the years from 1980 to 2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991 and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see “Data Sources” below). Bird observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of birds of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was surveyed more than once, densities were averaged, with an adjustment made for effort.

The seasonal high-use areas on map d were developed using a similar approach as for Maps a, b and c, but the data were binned into 10’x10’ cells. For each season, the cells with densities in the top 20% of non-zero values were designated “high use” for that season. Cells were scored for “high use” in one, two, or three seasons and are depicted by color. To provide a relative reference for the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season).

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

RESULTS AND DISCUSSION

Ashy storm-petrel is endemic to the California Current and is considered by the State to be a “Species of Special Concern”; a major colony is at the Farallon Islands. It is common in the study area and the most abundant storm-petrel in waters of the central California national marine sanctuaries. Surveys recorded 1,472 sightings of 4,339 individuals.

A multiple regression model of nine variables explained 17.3% of variation in cell density, with important explanatory variables being ENSO period (i.e., periods of unusually warm or cold ocean temperature), season, and year; see Table 19. The species was more abundant during the Oceanic Season and during years of La Niña, indicating that when ocean temperatures were cold, Ashy storm-petrels were concentrated closer to the Farallon breeding colony, which they visit only at night. During nesting (Upwelling Season), this species occupies waters mainly over the outer slope (mean depth of occurrence $1,615 \pm 52$ m), mostly outside of National Marine Sanctuary boundaries. During the period of molt (Oceanic Season), ashy storm-petrels move inshore to frequent shallower slope waters (mean depth of occurrence $1,144 \pm 61$ m) and a large concentration occurred over the Monterey Bay canyon as shown in maps on upwelling and seasonal high use areas.

In recent years, however, this post-breeding concentration has shifted to the area around Cordell Bank (not shown on the maps). As the species begins its seasonal return to the Farallon nesting colony (Davidson Current Season), they again shift north to deeper waters of the outer slope (mean depth of occurrence then was $2,579 \pm 121$ m). The species seems to be most dispersed during the Davidson Current Season, but in all seasons the Farallon Escarpment is by far its most important area.

Overall, ashy storm-petrel numbers increased from 1985 to 2002 in a curvilinear fashion: steeper increase in numbers between 1985 and 1992, followed by a less steep increase to 2002.

This species feeds on invertebrates and larval fish found at the surface. See Tables 15 and 16 for related summary information.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

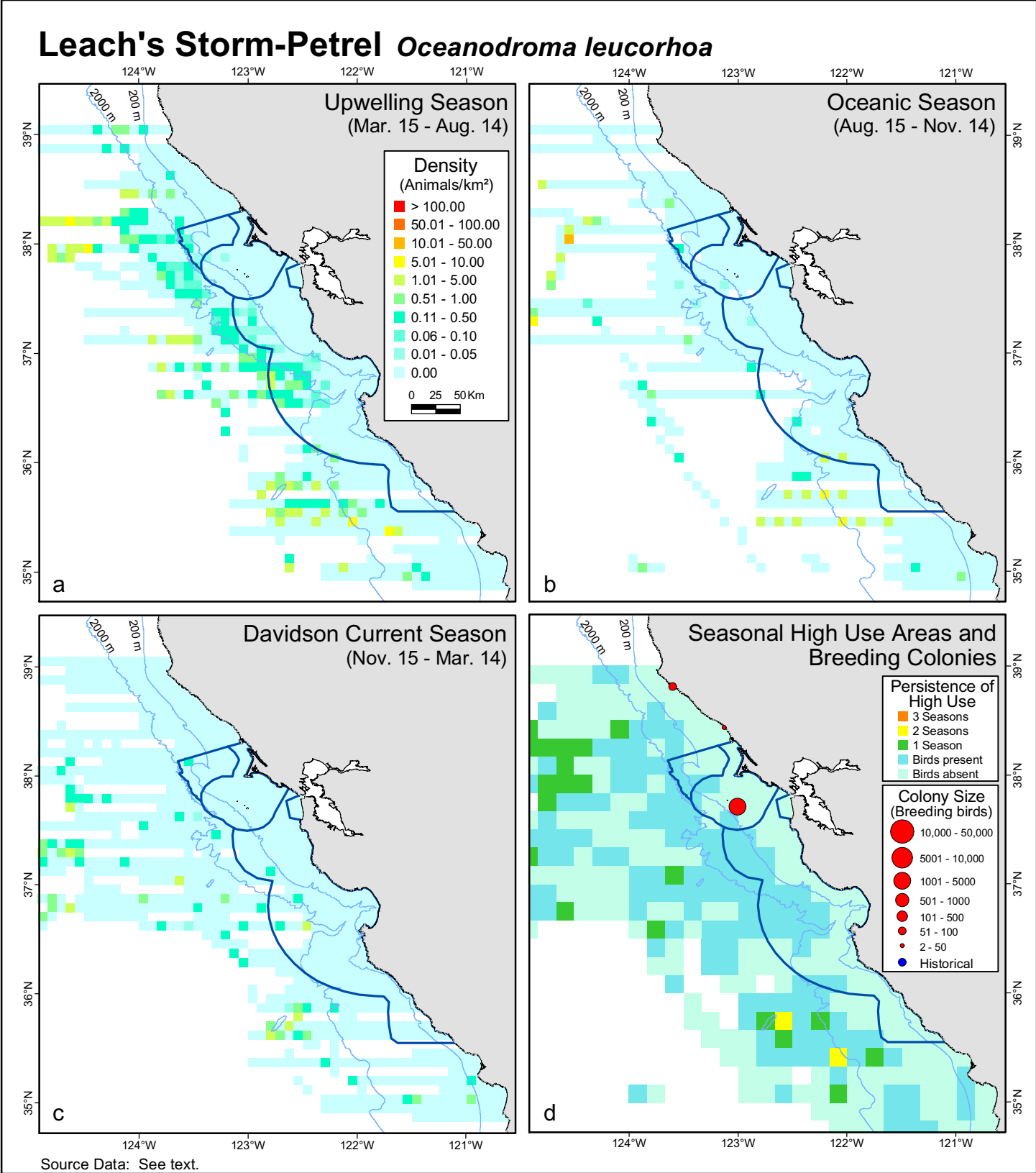


Figure 46. Leach's storm-petrel, seasonal density, high use areas, and breeding colonies.

ABOUT THESE MAPS

Figures 46a, b, and c show the density (birds/km²) of Leach's storm-petrel in the Upwelling, Oceanic, and Davidson Current seasons, displayed in five minute latitude by five minute longitude cells. Densities are based on the combined data sets of several studies (see "Methods" and "Data Sources" below). The color and mapping intervals were customized to show the most structure and to highlight significant areas, while allowing comparisons among marine bird species. Cells that were surveyed but in which no Leach's storm-petrels were observed have a density of zero. Areas not surveyed appear white; no information is available for these areas. Blue lines indicate the boundaries of the National Marine Sanctuaries in the study area: Cordell Bank, Gulf of the Farallones, and Monterey Bay. An additional set of maps was done for this species to show the offshore extent of its distribution; these maps are included on the CD-ROM.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence and abundance in the study area, map d shows seasonal high-use areas, displayed in 10 minute latitude by 10 minute longitude cells, and breeding colonies. The seasonal high use map provides a further synthesis of densities presented in Maps a, b and c, and portrays the relative importance of various areas to the species. Areas with consistently high use are highlighted on this map. To provide a relative reference for the "high use" areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there), or present but at lesser concentrations in any particular season. See the "Methods" section below for further explanation of seasonal high-use areas. Breeding colonies are also shown; the relative size of the symbols indicates the colony size. An additional set of maps was developed for this species to include the offshore extent of its distribution. These maps are on the CD-ROM.

Because the sighting data for this species extends beyond the western extent of the standard map frame shown here, additional maps were made that include a greater western extent. These maps (with the word "pelagic" in the filename) are included on the CDROM.

DATA SOURCES

Densities for marine birds at sea are based on data from eight survey programs conducted between 1980 and 2001, which were combined into a new MMS-CDAS data set (MMS, 2001) using software (CDAS) developed for the Minerals Management Service. Of the data sets on the original MMS-CDAS CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program is ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey

programs were converted to a compatible format for analysis (see section overview for details on individual data sets).

Data sources for aerial, at-sea data include MMS-CDAS (MMS, 2001), California Department of Fish and Game, Office of Spill Prevention and Response (CDF&G-OSPR, unpublished data). Early data were collected using methods described by Briggs et al. (1983, 1987b); more recent data were collected using updated technology but using the same general method. Data sources for ship-based survey data include: David Ainley of H. T. Harvey and Associates and Carol Keiper of Oikonos (unpublished data; see Oedekoven et al., 2001 for details on survey methods); and Lisa T. Ballance, from the Ecology Program of the Southwest Fisheries Science Center, NMFS, NOAA (unpublished data). Data on Leach's storm-petrel colonies were obtained from Carter et al. (1992, and supplements).

Although the at-sea data span the years from 1980 to 2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991, and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources" below). Bird observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of birds of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was surveyed more than once, densities were averaged, with an adjustment made for effort.

The seasonal high-use areas on map d were developed using a similar approach as for Maps a, b and c, but the data were binned into 10'x10' cells. For each season, the cells with densities in the top 20% of non-zero values were designated "high use" for that season. Cells were scored for "high use" in one, two, or three seasons and are depicted by color. To provide a relative reference for the "high use" areas, cells are

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season).

RESULTS AND DISCUSSION

The Leach’s storm-petrel, which has a breeding population numbering in the millions in Alaska, is represented south to Baja California by smaller colonies as latitude decreases. In comparison, the estimated 12,551 birds breeding along the California coast is miniscule (Carter et al, 1992). This, and the fact that this species is highly migratory, suggests that many of the birds seen in the study areas are migrants from the north. This was also indicated by the lack of importance in a multiple regression model of distance to colony as a factor explaining this species’ variation in cell density; see Table 19. Surveys recorded 1,118 sightings of 1,576 individuals, although survey effort was sparse in the offshore waters this species frequents.

This common species frequents waters much farther offshore than the other storm-petrels, i.e. well beyond the continental slope. Thus, the National Marine Sanctuary boundaries (and most of the data sets in this study) do not encompass much of this species’ preferred habitat. The species was most abundant during the Upwelling Season (breeding) and occurred in greater numbers closer to the coast. They visit the Farallon colony only at night, but are at-sea during the day. During the Oceanic and Davidson Current seasons few occurred near the shelf. The birds present during the latter two seasons likely were migrants from more northern populations. Given the huge North Pacific population, the number recorded during surveys in the study area was relatively small, because they were mostly far offshore and not observed as often in the surveys available for this assessment.

Yet, a multiple regression model of nine independent variables explained 28.4% of variation in cell density, indicating that this species responded consistently to the variables examined. Most important of the nine variables were season, distance to the 2000 m isobath, and ENSO period (periods of unusually warm or cold ocean temperature); see Table 19. Abundance of this species in the study area has increased between 1985 and 2002, and it was more abundant during periods of warm-water conditions.

This species feeds on invertebrates captured at the surface. See Tables 15 and 16 for related summary information.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

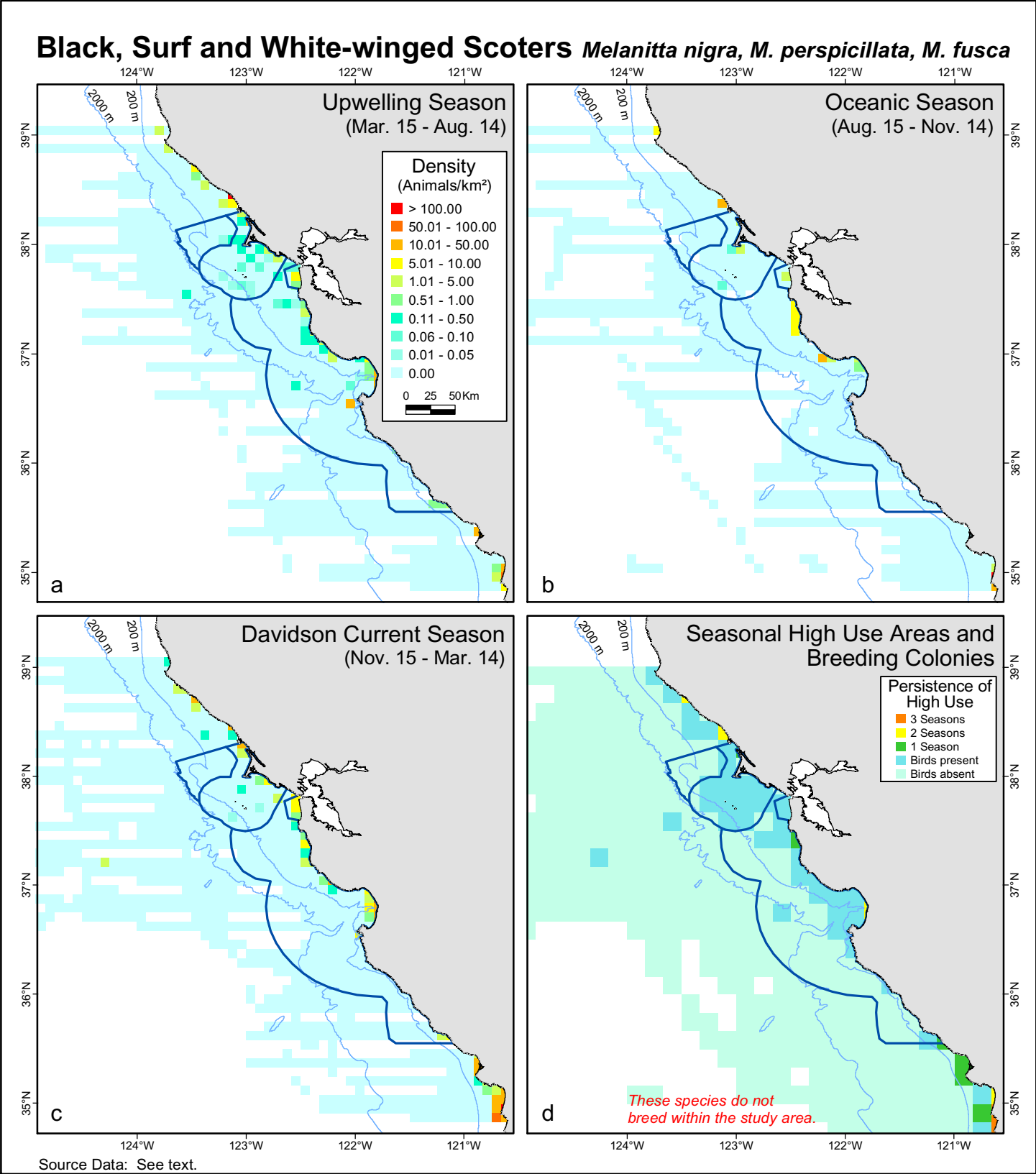


Figure 47. Black, surf and white-winged scoters, seasonal density and high use areas.

ABOUT THESE MAPS

Figures 47a, b, and c show the combined density (birds/km²) of three scoter species (white-winged, surf, and black) in the Upwelling, Oceanic, and Davidson Current seasons, displayed in five minute latitude by five minute longitude cells. Densities are based on the combined data sets of several studies (see “Methods” and “Data Sources” below). The color and mapping intervals were customized to show the most structure and to highlight significant areas, while allowing comparisons among marine bird species. Cells that were surveyed but in which no scoters were observed have a density of zero. Areas not surveyed appear white; no information is available for these areas. Blue lines indicate the boundaries of the National Marine Sanctuaries in the study area: Cordell Bank, Gulf of the Farallones, and Monterey Bay.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence and abundance in the study area, map d shows seasonal high-use areas, displayed in 10 minute latitude by 10 minute longitude cells. The seasonal high use map provides a further synthesis of densities presented in Maps a, b and c, and portrays the relative importance of various areas to the species. Areas with consistently high use are highlighted on this map. To provide a relative reference for the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there), or present but at lesser concentrations in any particular season. See the “Methods” section below for further explanation of seasonal high-use areas.

DATA SOURCES

Densities for marine birds at sea are based on data from eight survey programs conducted between 1980 and 2001, which were combined into a new MMS-CDAS data set (MMS, 2001) using software (CDAS) developed for the Minerals Management Service. Of the data sets on the original MMS-CDAS CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal.. Of these, the OSPR survey program is ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis (see section overview for details on individual data sets).

Data sources for aerial, at-sea data include MMS-CDAS (MMS, 2001), California Department of Fish and Game, Office of Spill Prevention and (CDF&G-OSPR, unpublished data). Early data were collected using methods described by Briggs et al. (1983, 1987b); more recent data were collected using updated technology but using the same general method. Data sources for ship-based survey data include: David Ainley of H. T. Harvey and Associates and Carol Keiper of Oikonos (unpublished data; see Oedekoven et al., 2001 for details on survey methods); and

Lisa T. Ballance, from the Ecology Program of the Southwest Fisheries Science Center, NMFS, NOAA (unpublished data).

Although the at-sea data span the years from 1980 to 2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991, and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see “Data Sources” below). Bird observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of birds of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was surveyed more than once, densities were averaged, with an adjustment made for effort.

The seasonal high-use areas on map d were developed using a similar approach as for Maps a, b and c, but the data were binned into 10’x10’ cells. For each season, the cells with densities in the top 20% of non-zero values were designated “high use” for that season. Cells were scored for “high use” in one, two, or three seasons and are depicted by color. To provide a relative reference for the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season).

RESULTS AND DISCUSSION

The distribution of white-winged, surf, and black scoters in the north/central California study area is very similar to that of the grebes (see above), although they are somewhat less abundant and found closer to shore. There they forage mostly just outside the surf break. On the outer coast, the abundant surf scoter dominates over the other two scoters, and black scoters, which occur in more protected waters, are rare. Surveys recorded 1,787 sightings of scoters that included 42,691 individuals; more than half were identified as surf scoter. The most important areas for surf scoters within the study area is

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

the San Francisco Bay tidal plume, especially southward along the Pacifica shore to Half Moon Bay, and the shallow parts of Bodega, Monterey, Estero, and San Luis Obispo bays. These birds nest in the arctic tundra along the north slope of North America; specific nesting areas of birds found wintering in the marine sanctuary boundaries have not been identified.

The apparent movement of these sea ducks' offshore, i.e. to the outer parts of the Gulf of the Farallones, in the Upwelling Season is an artifact of their migration north or south, to or from Alaskan breeding areas. That portion of the population wintering south of central California takes the shortest distance across the Gulf of the Farallones; the offshore density cells highlighted in the maps is a record of flying scoters.

These scoters do not forage far from the mainland beach, where they eat invertebrates; several dozen usually winter around the Farallon Islands. The inshore distribution of these ducks, like the grebes, makes them vulnerable to coastal oil spills. See Tables 15 and 16 for related summary information.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

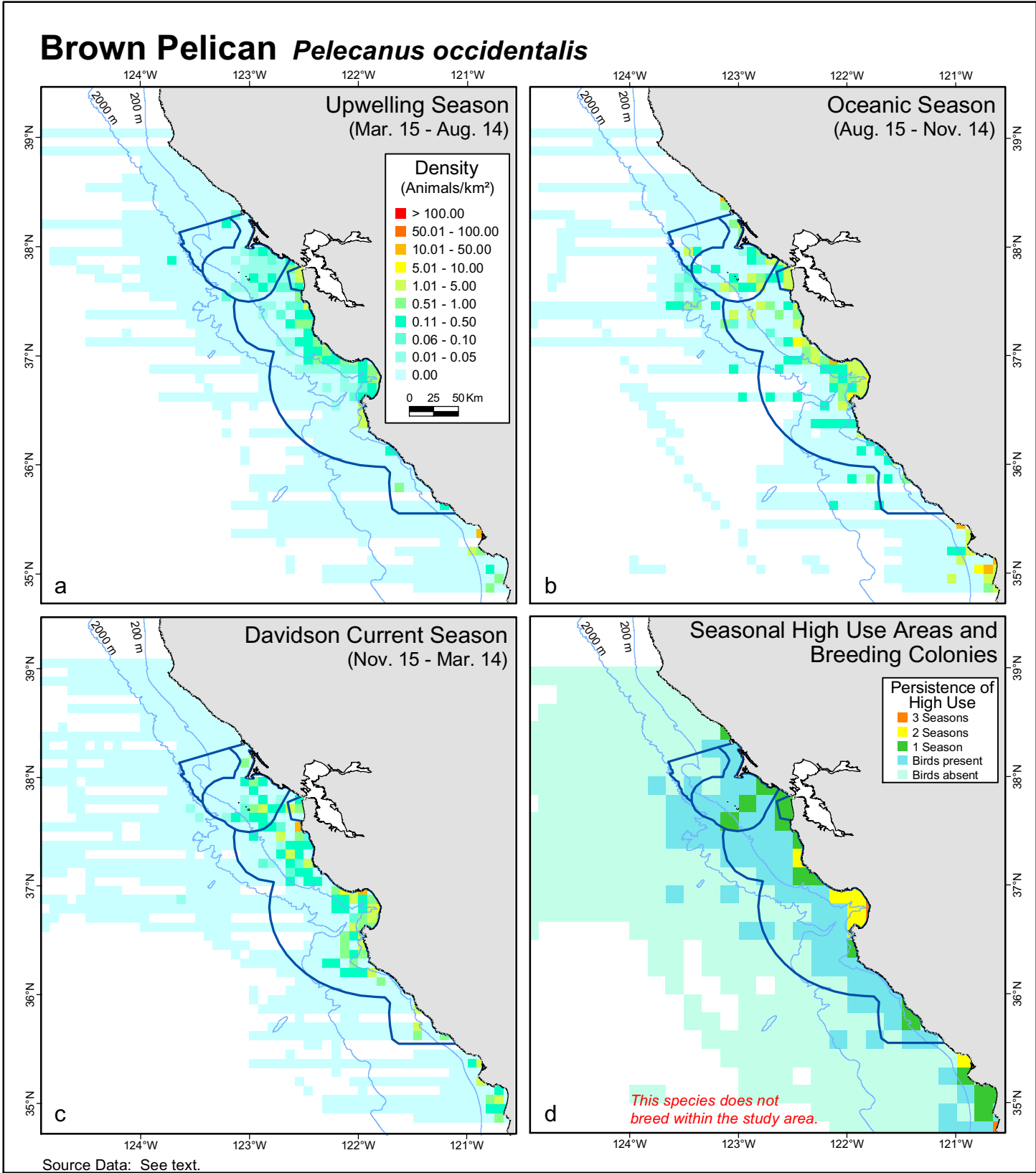


Figure 48. Brown pelican, seasonal density and high use areas.

ABOUT THESE MAPS

Figures 48a, b, and c show the density (birds/km²) of brown pelicans in the Upwelling, Oceanic, and Davidson Current seasons, displayed in five minute latitude by five minute longitude cells. Densities are based on the combined data sets of several studies (see “Methods” and “Data Sources” below). The color and mapping intervals were customized to show the most structure and to highlight significant areas, while allowing comparisons among marine bird species. Cells that were surveyed but in which no brown pelicans were observed have a density of zero; areas not surveyed are white. Blue lines indicate the boundaries of the National Marine Sanctuaries in the study area: Cordell Bank, Gulf of the Farallones, and Monterey Bay.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence and abundance in the study area, map d shows seasonal high-use areas, displayed in 10 minute latitude by 10 minute longitude cells, and breeding colonies (in this species’ case, a site where it bred in the past). The seasonal high use map provides a further synthesis of densities presented in Maps a, b and c, and portrays the relative importance of various areas to the species. Areas with consistently high use are highlighted on this map. To provide a relative reference for the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there), or present but at lesser concentrations in any particular season. See the “Methods” section below for further explanation of seasonal high-use areas. Breeding colonies are also shown; the relative size of the symbols indicates the colony size.

DATA SOURCES

Densities for marine birds at sea are based on data from eight survey programs conducted between 1980 and 2001, which were combined into a new MMS-CDAS data set (MMS, 2001) using software (CDAS) developed for the Minerals Management Service. Of the data sets on the original MMS-CDAS CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program is ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis (see section overview for details on individual data sets).

Data sources for aerial, at-sea data include MMS-CDAS (MMS, 2001), and California Department of Fish and Game, Office of Spill Prevention and Response (CDF&G-OSPR, unpublished data). Early data were collected using methods described by Briggs et al. (1983, 1987b); more recent data were collected using updated technology but using the same general method. Data sources for ship-based survey data include: David Ainley

of H. T. Harvey and Associates and Carol Keiper of Oikonos (unpublished data; see Oedekoven et al., 2001 for details on survey methods); and Lisa T. Ballance, from the Ecology Program of the Southwest Fisheries Science Center, NMFS, NOAA (unpublished data). Data on brown pelican colonies were obtained from Carter et al. (1992, and supplements).

Although the at-sea data span the years from 1980 to 2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991 and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see “Data Sources” below). Bird observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of birds of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was surveyed more than once, densities were averaged, with an adjustment made for effort.

The seasonal high-use areas on map d were developed using a similar approach as for Maps a, b and c, but the data were binned into 10’x10’ cells. For each season, the cells with densities in the top 20% of non-zero values were designated “high use” for that season. Cells were scored for “high use” in one, two, or three seasons and are depicted by color. To provide a relative reference for the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season).

RESULTS AND DISCUSSION

Brown pelicans are included in the State and Federal endangered species lists, and are common year-round in Monterey Bay and to the south. Surveys recorded 1,447 sightings of 3,003 individuals.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

This population breeds on selected islands off Baja Mexico and southern California, with small colonies extending north to the Channel Islands. Brown pelicans once bred on rocks off Monterey, but are now concentrated in the central California study area at roosts such as Morro Rock, Monterey Breakwater, Año Nuevo Island, Southeast Farallon Island, Bird Rock in Monterey county, and Bodega Rock. Nesting occurs in southern California and Baja Mexico and begins in November and can extend through June, when the species is most sparse in the central California study area. The brown pelican is most abundant in the study area during the Oceanic Season; the species' presence then constitutes a post-breeding increase from southern breeding grounds.

North of Monterey and Estero/San Luis Obispo bays, this species' presence is much more seasonal and dependent on ocean climate. Most sightings in the Gulf of the Farallones during the Davidson Current and Upwelling seasons occurred during warm-water years, often associated with the species choosing to forego breeding at southern colonies. Thus, wintering birds may remain in central California waters, while others may move farther north than usual at that time. In most cool-or coldwater years, adults are not abundant north of Monterey Bay during these two seasons. This could change, however, as sardines, an important prey item, continue to increase in California waters.

The species frequents waters within several miles of shore (mean distance to land was 10.3 ± 0.4 km) and rarely occurs in waters deeper than the shelf break (mean depth was 266 ± 21 m). Consistent with these patterns are results of a multiple regression model of nine independent variables, which explained 15.2% of the variation; important variables were season, and inverse relationships to distance to land and latitude; see Table 19. Therefore, the broad shelf of central California is well suited to this species; its occurrence becomes sporadic north of Point Reyes. Inshore Monterey, Estero, and San Luis Obispo bays are especially important, where this species is common year round; the San Francisco Bay tidal plume is also important. Abundance of this species in the study area has increased between 1985 and 2002.

This species preys exclusively on fish, especially anchovies, mackerel, and sardines, that it catches by plunging to just below the surface. See Tables 15 and 16 for related summary information.

Section 2.3: BIOGEOGRAPHY OF MARINE BIRDS

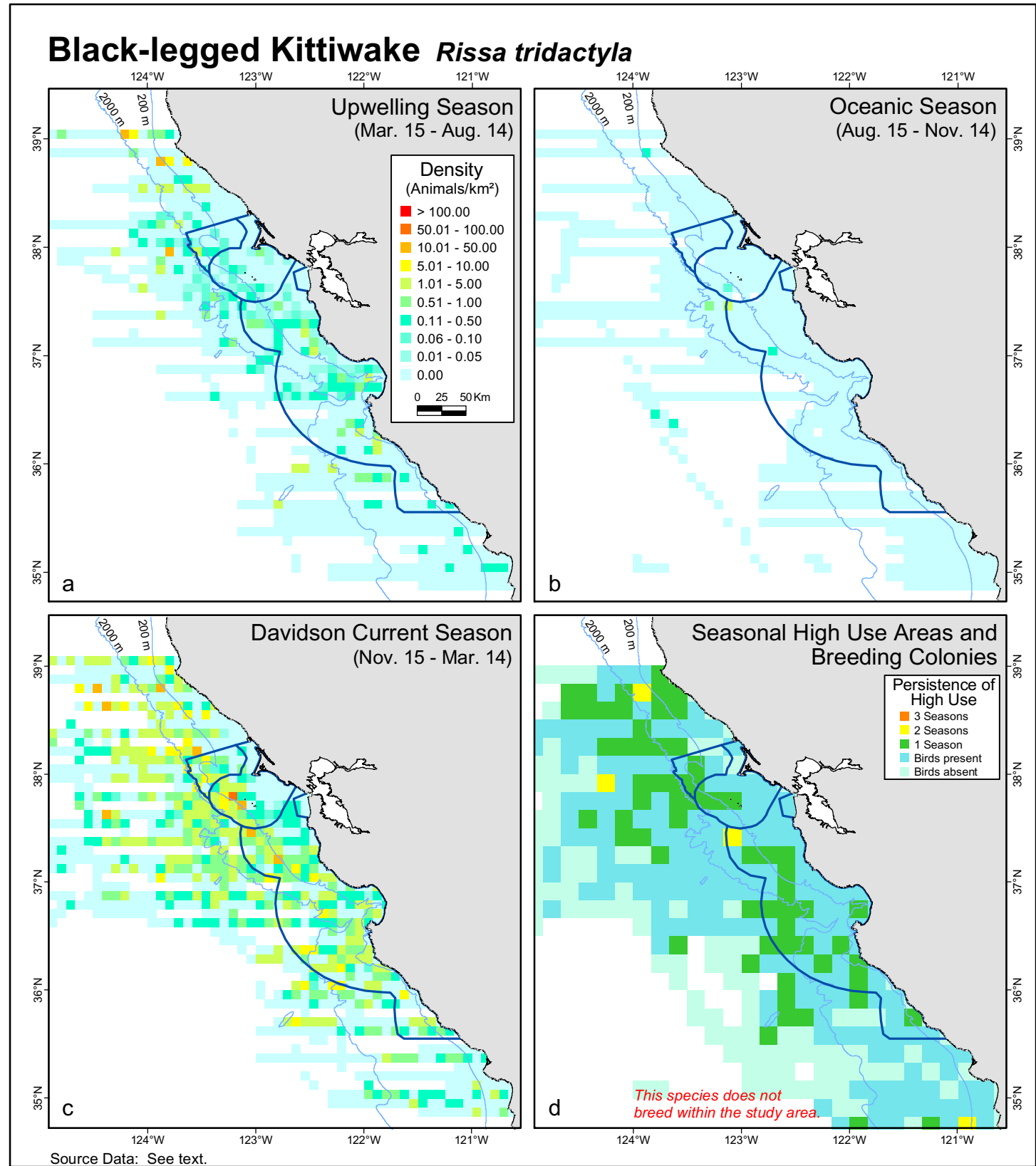


Figure 49. Black-legged kittiwake, seasonal density and high use areas.

ABOUT THESE MAPS

Figures 49a, b, and c show the density (birds/km²) of black-legged kittiwakes in the Upwelling, Oceanic, and Davidson Current seasons, displayed in five minute latitude by five minute longitude cells. Densities are based on the combined data sets of several studies (see "Methods" and "Data Sources" below). The color and mapping intervals were customized to show the most structure and to highlight significant areas, while allowing comparisons among marine bird species. Cells that were surveyed but in which no black-legged kittiwakes were observed have a density of zero. Areas not surveyed appear white; no information is available for these areas. Blue lines indicate the boundaries of the National Marine Sanctuaries in the study area: Cordell Bank, Gulf of the Farallones, and Monterey Bay.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence and abundance in the study area, map d shows seasonal high-use areas, displayed in 10 minute latitude by 10 minute longitude cells. The seasonal high use map provides a further synthesis of densities presented in Maps a, b and c, and portrays the relative importance of various areas to the species. Areas with consistently high use are highlighted on this map. To provide a relative reference for the "high use" areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there), or present but at lesser concentrations in any particular season. See the "Methods" section below for further explanation of seasonal high-use areas.

DATA SOURCES

Densities for marine birds at sea are based on data from eight survey programs conducted between 1980 and 2001, which were combined into a new MMS-CDAS data set (MMS, 2001) using software (CDAS) developed for the Minerals Management Service. Of the data sets on the original MMS-CDAS CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program is ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis (see section overview for details on individual data sets).

Data sources for aerial, at-sea data include MMS-CDAS (MMS, 2001), and California Department of Fish and Game, Office of Spill Prevention and Response (CDF&G-OSPR, unpublished data). Early data were collected using methods described by Briggs et al. (1983, 1987b); more recent data were collected using updated technology but using the same general method. Data sources for ship-based survey data include: David Ainley of H. T. Harvey and Associates and Carol Keiper of Oikonos (unpublished data; see Oedekoven et al., 2001 for details

on survey methods); and Lisa T. Ballance, from the Ecology Program of the Southwest Fisheries Science Center, NMFS, NOAA (unpublished data).

Although the at-sea data span the years from 1980 to 2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991, and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources" below). Bird observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of birds of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was surveyed more than once, densities were averaged, with an adjustment made for effort.

The seasonal high-use areas on map d were developed using a similar approach as for Maps a, b and c, but the data were binned into 10'x10' cells. For each season, the cells with densities in the top 20% of non-zero values were designated "high use" for that season. Cells were scored for "high use" in one, two, or three seasons and are depicted by color. To provide a relative reference for the "high use" areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season).

RESULTS AND DISCUSSION

The black-legged kittiwake, like the northern fulmar, breeds on islands along the northern coast of North America and Asia, but large numbers 'winter' in the study area off central California. It is a common species in the study area; surveys recorded 2,079 sightings of 5,003 individuals. A multiple-regression model of eight independent variables explained 28.9% of variation in cell density; important variables were season, ENSO period (i.e., periods of climatic variation), and year (increasing abundance). The black-legged kittiwake was most abundant in the

Section 2.3: BIOGEOGRAPHY OF MARINE BIRDS

study area during the Davidson Current Season and less so during the early Upwelling Season; it was largely absent during the late-Upwelling Season and Oceanic Season (which corresponds to the breeding season at northern-latitude nesting sites). Abundance was highest during periods of La Niña. Most kittiwakes occurred in waters overlying the continental slope, and deeper waters seaward of National Marine Sanctuary boundaries (mean depth of occurrence was 1,408 m; mean distance from shore was 29.0 km). A minority of kittiwakes occurred over the shelf, mainly where the shelf is narrow. There was an “invasion” of kittiwakes in 1999, coincident with the beginning of the cold-water regime shift (see below).

This species feeds on fish and pelagic invertebrates that they catch by dipping and plunging to the surface. No studies of kittiwake diet at sea were available. See Tables 15 and 16 for related summary information.

Section 2.3: BIOGEOGRAPHY OF MARINE BIRDS

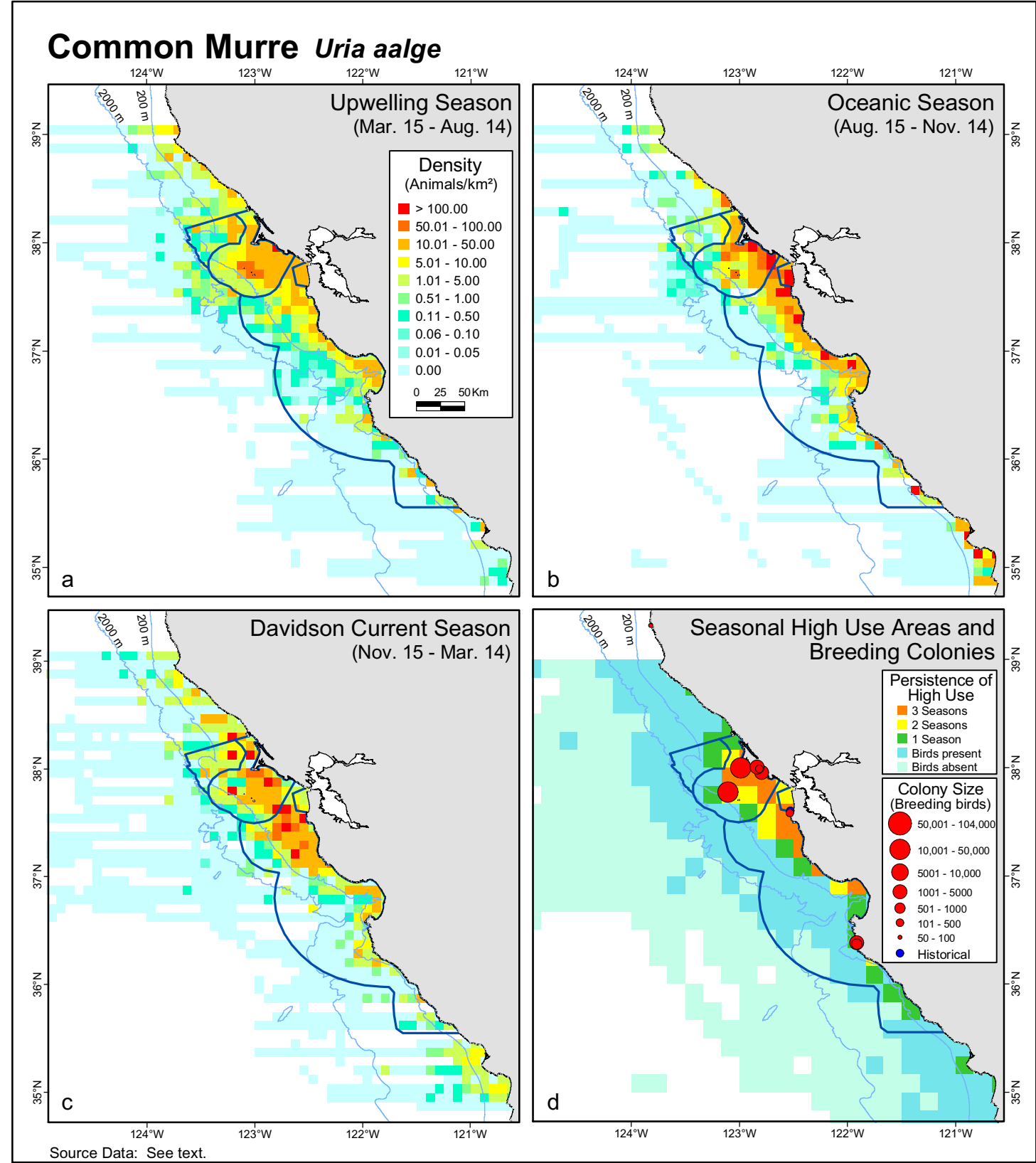


Figure 50. Common murre, seasonal density and high use areas and breeding colonies.

ABOUT THESE MAPS

Figures 50a, b, and c show the density (birds/km²) of common murre in the Upwelling, Oceanic, and Davidson Current seasons, displayed in five minute latitude by five minute longitude cells. Densities are based on the combined data sets of several studies (see “Methods” and “Data Sources” below). The color and mapping intervals were customized to show the most structure and to highlight significant areas, while allowing comparisons among marine bird species. Cells that were surveyed but in which no common murres were observed have a density of zero. Areas not surveyed appear white; no information is available for these areas. Blue lines indicate the boundaries of the National Marine Sanctuaries in the study area: Cordell Bank, Gulf of the Farallones, and Monterey Bay.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence and abundance in the study area, map d shows seasonal high-use areas, displayed in 10 minute latitude by 10 minute longitude cells, and breeding colonies. The seasonal high use map provides a further synthesis of densities presented in Maps a, b and c, and portrays the relative importance of various areas to the species. Areas with consistently high use are highlighted on this map. To provide a relative reference for the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there), or present but at lesser concentrations in any particular season. See the “Methods” section below for further explanation of seasonal high-use areas. Breeding colonies are also shown; the relative size of the symbols indicates the colony size.

DATA SOURCES

Densities for marine birds at sea are based on data from eight survey programs conducted between 1980 and 2001, which were combined into a new MMS-CDAS data set (MMS, 2001) using software (CDAS) developed for the Minerals Management Service. Of the data sets on the original MMS-CDAS CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program is ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis (see section overview for details on individual data sets).

Data sources for aerial, at-sea data include MMS-CDAS (MMS, 2001), and California Department of Fish and Game, Office of Spill Prevention and Response (CDF&G-OSPR, unpublished data). Early data were collected using methods described by Briggs et al. (1983, 1987b); more recent data were collected using updated technology but using the same general method.

Data sources for ship-based survey data include: David Ainley of H. T. Harvey and Associates and Carol Keiper of Oikonos (unpublished data; see Oedekoven et al., 2001 for details on survey methods); and Lisa T. Ballance, from the Ecology Program of the Southwest Fisheries Science Center, NMFS, NOAA (unpublished data). Data on common murre colonies were obtained from Carter et al. (1992), with updates for Devil’s Slide (Gerry McChesney, USFWS, pers. comm) and South Farallon Island (Warzybok et al. 2002).

Although the at-sea data span the years from 1980 to 2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991, and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see “Data Sources” below). Bird observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of birds of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was surveyed more than once, densities were averaged, with an adjustment made for effort.

The seasonal high-use areas on map d were developed using a similar approach as for Maps a, b and c, but the data were binned into 10’x10’ cells. For each season, the cells with densities in the top 20% of non-zero values were designated “high use” for that season. Cells were scored for “high use” in one, two, or three seasons and are depicted by color. To provide a relative reference for the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season).

RESULTS AND DISCUSSION

The common murre is very abundant in the study area, being the second most numerous marine bird in Central California. There have been 21,893 sightings of 141,964 individuals,

Section 2.3: BIOGEOGRAPHY OF MARINE BIRDS

with the ratio between these numbers indicating that murres usually occur in flocks. The species nests at a complex of related and densely occupied colonies including the Farallon Islands, Point Reyes, Double Point (including Point Resistance and Millers Point Rocks), and a small colony at Devils Slide. This complex constitutes one of the largest, if not the largest, breeding population of this species south of Alaska. Two small, disjunct breeding colonies, the southernmost for this species, occur off the Big Sur coast.

Based on analysis of the data, common murres reside in the study area year-round, being particularly abundant in waters overlying the shelf and upper slope (mean depth of 110 ± 5 m), with little seasonal change in distribution. Murre densities, however, were, in general, significantly higher during the Upwelling Season, probably because the entire population is present at that time. During the other seasons, some breeding individuals disperse outside of the study area. A multiple regression model of nine independent variables explained 52.3% of variation in density; especially through inverse relationships with distance to colony, ocean depth, and distance to land; see Table 19. No significant trend in common murre abundance existed between 1985 and 2002, and abundance was not affected by short-term climate fluctuations (e.g., periods of unusually warm or cold sea temperatures).

Near the large Farallon Islands colony during nesting, many murres range seaward beyond the continental slope (and outside sanctuary boundaries), perhaps as a response to increased intraspecific competition for prey at that time. As a result, the Farallon Escarpment became an area of high concentration as well as the Farallon Ridge and shelf waters inshore of it. Murres occur in Monterey Bay after nesting and mainly during the Oceanic Season. During years of unusually warm waters (and depleted prey), murres occur more frequently inshore, especially along the coast from Point Reyes south to Año Nuevo Island, the usual area of concentration during the relatively warm Oceanic Season.

This species is a deep diver (to 180m depth, Ainley et al, 2002) that feeds on fish and invertebrates. During winter and early spring, major prey include herring, market squid and euphausiids; this diet then shifts mostly to juvenile rockfish and anchovies in mid-summer. See Tables 15 and 16 for related summary information.

Section 2.3: BIOGEOGRAPHY OF MARINE BIRDS

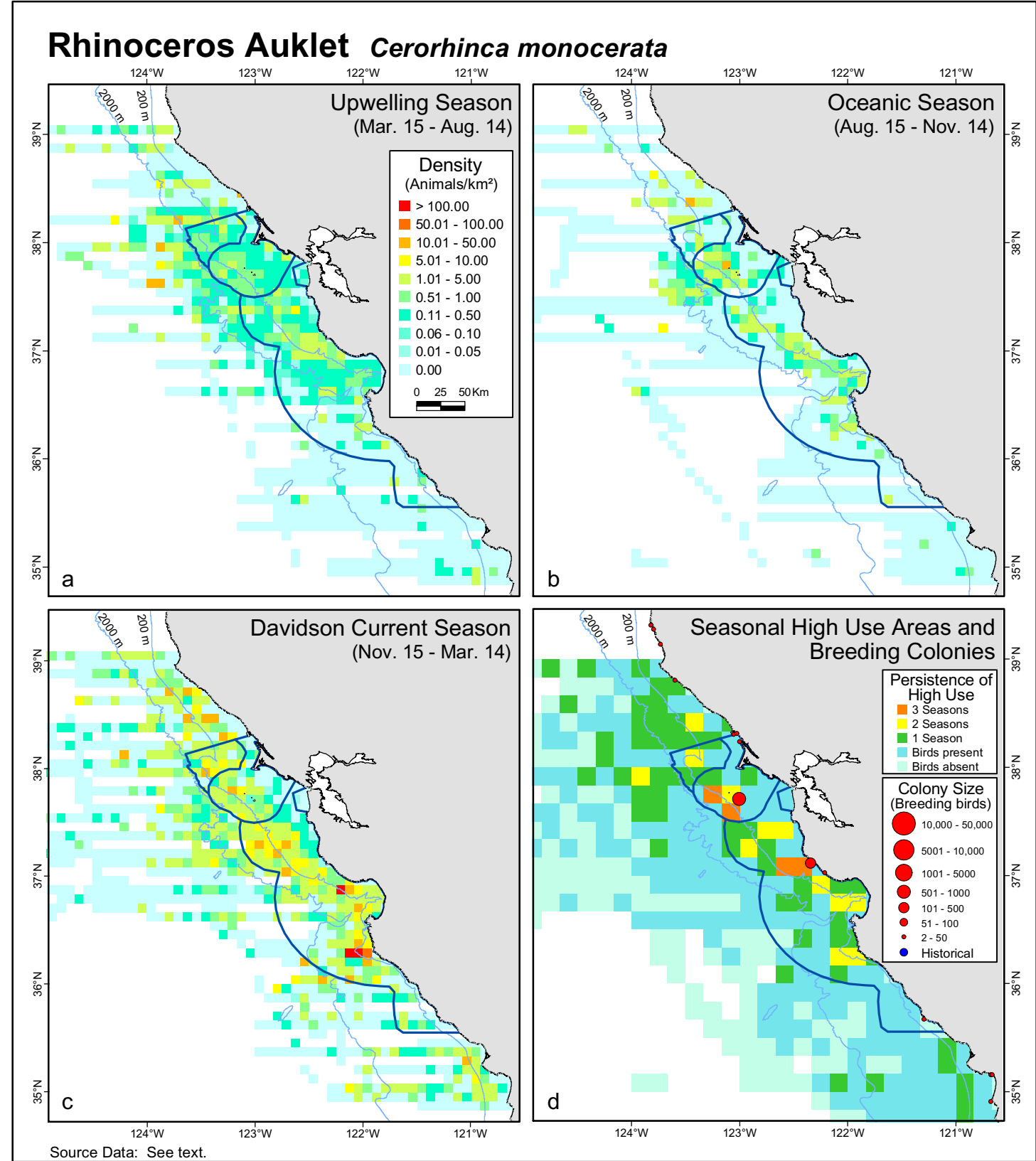


Figure 51. Rhinoceros auklet, seasonal density and high use areas and breeding colonies.

ABOUT THESE MAPS

Figures 51a, b, and c show the density (birds/km²) of Rhinoceros Auklet in the Upwelling, Oceanic, and Davidson Current seasons, displayed in five minute latitude by five minute longitude cells. Densities are based on the combined data sets of several studies (see “Methods” and “Data Sources” below). The color and mapping intervals were customized to show the most structure and to highlight significant areas, while allowing comparisons among marine bird species. Cells that were surveyed but in which no Rhinoceros Auklets were observed have a density of zero. Areas not surveyed appear white; no information is available for these areas. Blue lines indicate the boundaries of the National Marine Sanctuaries in the study area: Cordell Bank, Gulf of the Farallones, and Monterey Bay.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence and abundance in the study area, map d shows seasonal high-use areas, displayed in 10 minute latitude by 10 minute longitude cells, and breeding colonies. The seasonal high use map provides a further synthesis of densities presented in Maps a, b and c, and portrays the relative importance of various areas to the species. Areas with consistently high use are highlighted on this map. To provide a relative reference for the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there), or present but at lesser concentrations in any particular season. See the “Methods” section below for further explanation of seasonal high-use areas. Breeding colonies are also shown; the relative size of the symbols indicates the colony size.

DATA SOURCES

Densities for marine birds at sea are based on data from eight survey programs conducted between 1980 and 2001, which were combined into a new MMS-CDAS data set (MMS, 2001) using software (CDAS) developed for the Minerals Management Service. Of the data sets on the original MMS-CDAS CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program is ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis (see section overview for details on individual data sets).

Data sources for aerial, at-sea data include MMS-CDAS (MMS, 2001), and California Department of Fish and Game, Office of Spill Prevention and Response (CDF&G-OSPR, unpublished data). Early data were collected using methods described by Briggs et al. (1983, 1987b); more recent data were collected using updated technology but using the same general method. Data sources for ship-based survey data include: David Ainley

of H. T. Harvey and Associates and Carol Keiper of Oikonos (unpublished data; see Oedekoven et al., 2001 for details on survey methods); and Lisa T. Ballance, from the Ecology Program of the Southwest Fisheries Science Center, NMFS, NOAA (unpublished data). Data on breeding colonies in the study area were obtained from Carter et al. (1992), with most recent estimates for Año Nuevo from Thayer and Sydeman (2002).

Although the at-sea data span the years from 1980 to 2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991, and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see “Data Sources” below). Bird observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of birds of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was surveyed more than once, densities were averaged, with an adjustment made for effort.

The seasonal high-use areas on map d were developed using a similar approach as for Maps a, b and c, but the data were binned into 10’x10’ cells. For each season, the cells with densities in the top 20% of non-zero values were designated “high use” for that season. Cells were scored for “high use” in one, two, or three seasons and are depicted by color. To provide a relative reference for the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season).

RESULTS AND DISCUSSION

In the study area, this common species nests principally at the Farallon Islands; a smaller nesting population occurs at Año Nuevo. The Farallones constitute the southernmost large nesting colony. At-sea surveys recorded 5,415 sightings of

Section 2.3: BIOGEOGRAPHY OF MARINE BIRDS

15,454 individuals. Based on the analysis of the combined data sets described in this section, the abundance of Rhinoceros Auklets has increased significantly since the 1970s (Ainley et al. 1994). Based on patterns apparent in the maps, the current at-sea population probably far exceeds the estimates of nesting populations in central California (Michelle Hester, pers.comm.). Therefore, if there was more nesting habitat (e.g., burrows, holes, crevices on offshore islands), the nesting population would probably be much larger.

Rhinoceros auklets, which mainly visit colonies at night, occurred principally in waters overlying the slope (mean depth of occurrence was 762 ± 22 m), particularly the shelf break, and, including the Farallon Escarpment. A sizeable portion of the population occurs outside of the National Marine Sanctuary boundaries. This is especially true in the vicinity of the Gulf of the Farallones during the Upwelling (nesting) and Oceanic seasons, when these auklets occur farther offshore (mean depths were 791 m and 1,370 m, respectively). This expansion of habitat, causing a 'halo' of increased density around the islands, may be a response to the large numbers nesting at the Farallones, a pattern typical of the Western Gull and Common Murre (see those accounts). The species' concentration, especially along the shelf break and upper continental slope, is particularly evident during the Oceanic Season, when the nesting populations are no longer associated with colonies.

A multiple-regression model of nine independent variables explained 19.8% of variation in cell density; important variables were a negative relationship to distance to land, and positive ones to season and ocean depth; see Table 19. The relationship with season reflected a dramatic increase in abundance during the Davidson Current Season (mean density of 161 birds per 100km²) compared to the Upwelling and Oceanic seasons (mean densities of 48 and 62 birds per 100 km², respectively). This increase during the Davidson Current Season was likely due to an influx of birds from the north where much larger populations breed, compared to those of the study area.

This species feeds by diving, probably to relatively deep depths (100 m, Ainley and Boekelheide, 1990), capturing mostly fish but also euphuasiids. Important prey are juvenile rockfish, anchovy and saury. See Tables 15 and 16 for related summary information.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

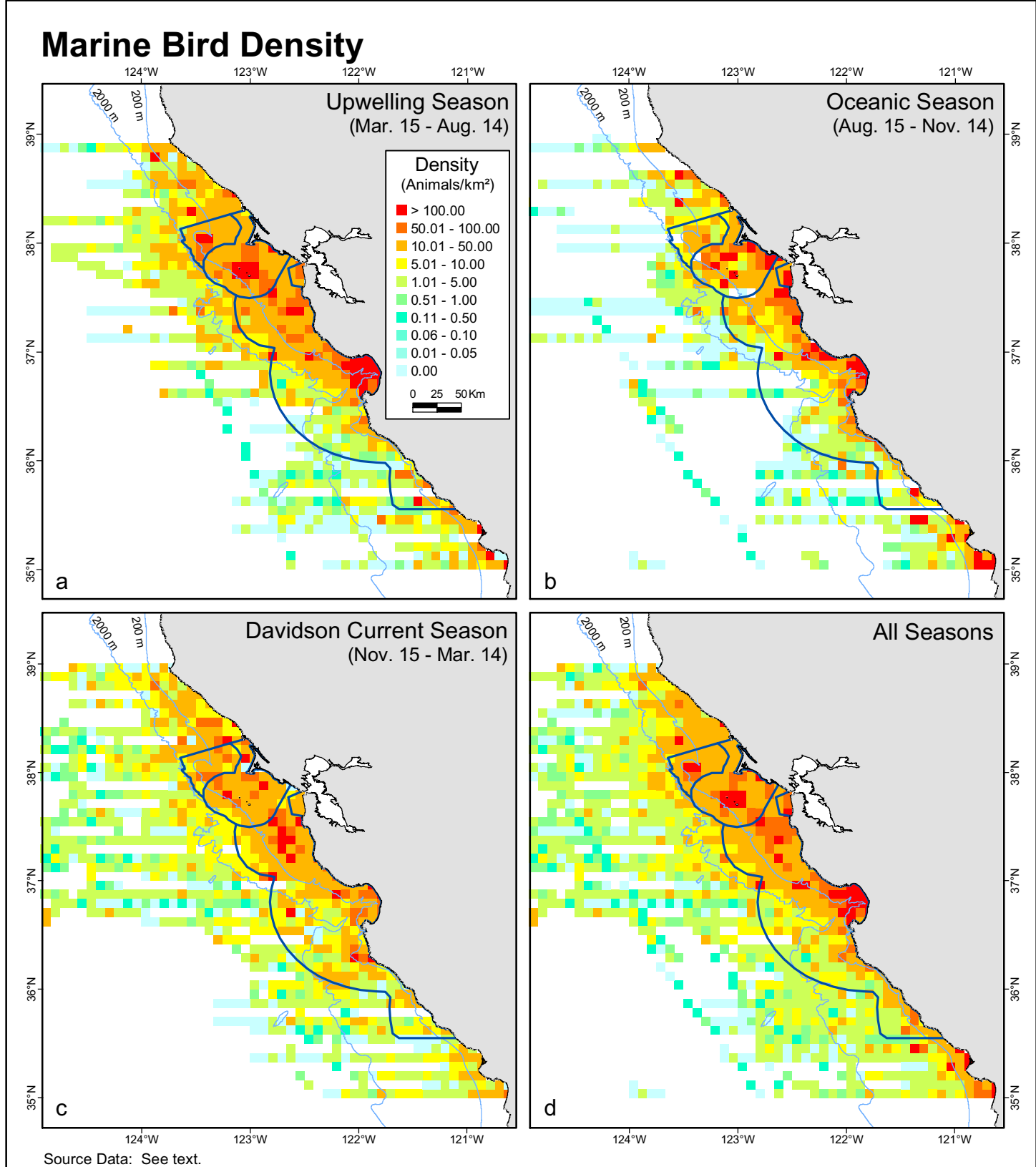


Figure 52. Marine bird density, by season and for all seasons.

ABOUT THESE MAPS

Figures 52a, b, and c show the combined density (birds/km²) of 76 species of marine birds in the Upwelling, Oceanic, and Davidson Current seasons, displayed in five minute latitude by five minute longitude cells. Map d shows density for all seasons and years combined. Densities are based on combined data of several studies (see “Methods” and “Data Sources” above). The color and mapping intervals were customized to show the most structure and highlight significant areas. Cells that were surveyed but in which no birds were observed have a density of zero; unsurveyed areas are white. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200 meter and 2,000 meter isobaths are also shown in blue.

DATA SOURCES

At-sea densities are based on data from eight survey programs conducted in 1980-2001, which were combined using software developed for MMS-CDAS (2001) and expanded for this project. Of the data sets on the original CD-ROM, four aerial survey data sets provided data in the study area from Point Arena to Point Sal. Of these, one program was still ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis. See section introduction for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (MMS, 2001), and California Department of Fish and Game Office of Spill Prevention and Response (CDF&G-OSPR, unpublished data). Early data were collected using methods described by Briggs et al. (1987b); more recent data were collected using updated technology but the same general method. Data sources for ship-based survey data include: David Ainley and Carol Keiper (unpublished data; see Oedekoven et al., 2001 for details on survey methods).

Although the at-sea data span the years 1980 to 2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991, and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see “Data Sources” above). Observation and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data,

the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells. The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of marine birds seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was censused more than once, densities were averaged, with adjustment made for effort.

RESULTS AND DISCUSSION

Overall density is dominated by two abundant marine bird species: common murre and sooty shearwater.

Based on visual inspection of the maps, density was highest, during the Upwelling Season with cells of highest density most widespread as well. Except for a few highest-density ‘hot spots,’ (see Table 17) marine birds were distributed evenly at high density (>10 individuals per km²) over the shelf and slope from north to south in the study area. Particular hot spots were inshore Monterey Bay, Farallon Ridge and Cordell Bank. The pattern during this season generally matched the pattern apparent when all seasons were combined.

During the Oceanic Season, highest density areas increased in prevalence inshore. At that time, hot spots were the San Francisco Bay tidal plume, inshore near Año Nuevo, innermost Monterey Bay and San Luis Obispo Bay.

During the Davidson Current Season, birds shifted more to the mid-shelf.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

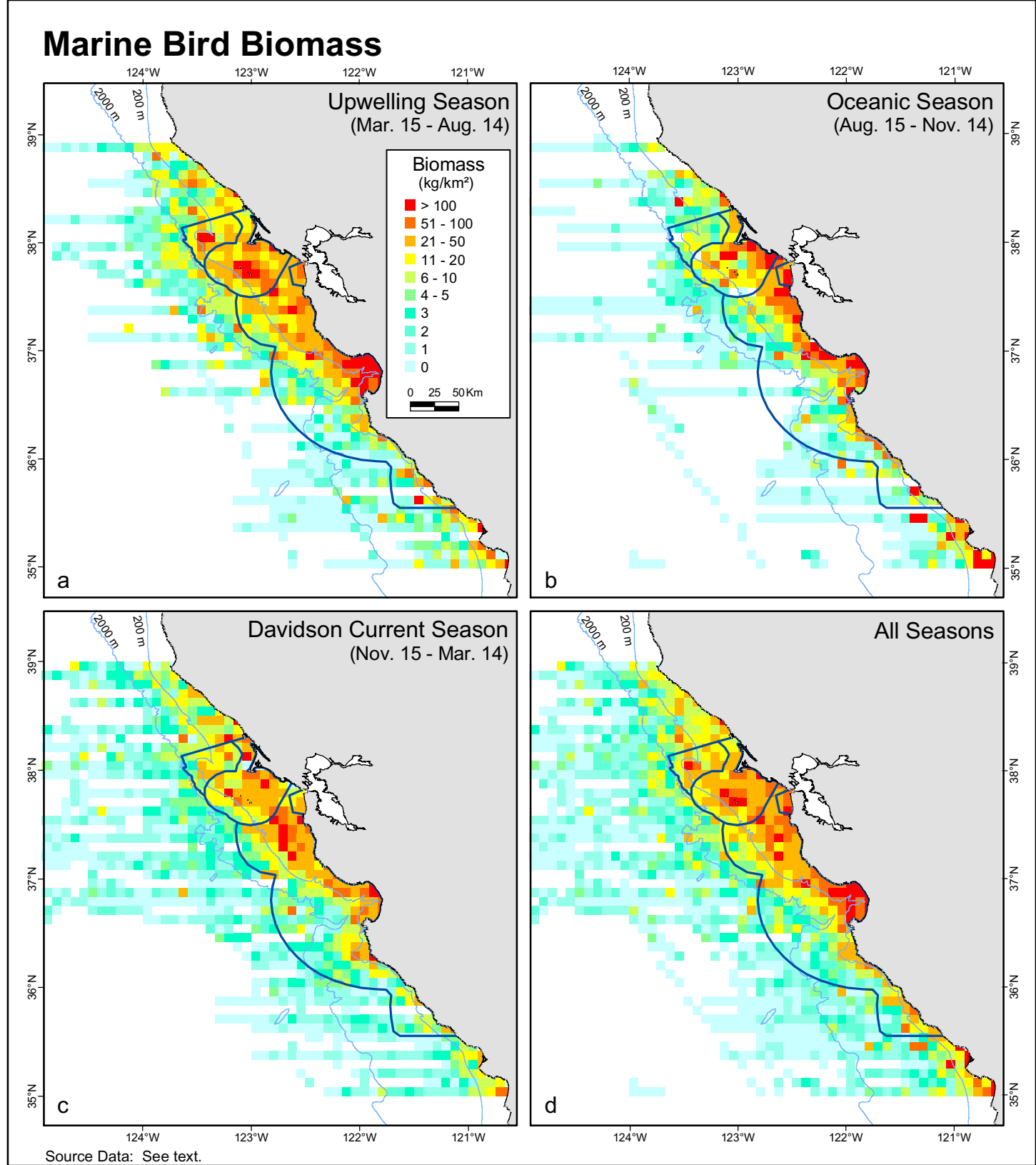


Figure 53. Marine bird biomass, by season and for all seasons.

ABOUT THESE MAPS

Figure 53a, b, and c shows total marine bird biomass (kg/km²) in each five minute latitude by five minute longitude cell for each oceanographic season and for all seasons combined 53d. Density for each of 76 species was multiplied by average body mass for that species. These products were summed for all species in a cell. The color and mapping intervals were customized to show the most structure and highlight significant areas. Cells that were surveyed but in which no birds were observed have a biomass density of zero; unsurveyed areas are white. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200 meter and 2,000 meter isobaths are also shown in blue.

DATA SOURCES

At-sea biomass densities are based on data from eight survey programs conducted in 1980-2001, which were combined using software developed for MMS-CDAS (2001) and expanded for this project. Of the data sets on the original CD-ROM, four aerial survey data sets provided data in the study area from Point Arena to Point Sal. Of these, one program was still ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis. See section introduction for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (MMS, 2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDF&G-OSPR), unpublished data. Early data were collected using methods described by Briggs et al. (1987b); more recent data were collected using updated technology but the same general method. Data sources for ship-based survey data include David Ainley and Carol Keiper (unpublished data; see Oedekoven et al., 2001 for details on survey methods). Although the at-sea data span the years 1980-2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991 and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

Data on average biomass for each species were derived from *Body Weights of 686 Species of North American Birds* (Dunning 1993). In a few instances, a species was not listed in this reference; in these cases, the biomass of a closely related bird of a similar size was used.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources"

above). Observation and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells. The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of marine birds seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was censused more than once, densities were averaged, with adjustment made for effort.

Once the weighted densities had been determined for each species in each cell, densities of each species were multiplied by the average body mass of that species. These 'biomass densities' were then summed for each cell and the results plotted.

RESULTS AND DISCUSSION

In general, the biomass maps are dominated by two, relatively heavy-bodied, numerically dominant species: common murre and sooty shearwater. These maps are also influenced, to a lesser degree, by the species identified as abundant in the study area (see Table 15).

Looking first at a summary of all seasons, high biomass densities occurred in the Gulf of the Farallones, especially around the Farallon Islands, the San Francisco Bay tidal plume, off Half-moon Bay, just south of Point Año Nuevo and in inner Monterey Bay.

During the Upwelling season, high biomass densities occurred over the shelf and upper slope with highest density areas occurring at Monterey Bay, Farallon Ridge, and Cordell Bank. The distribution of high biomass during the Upwelling Season mimicked that described in the all seasons map (map d).

During the Oceanic Season high biomass was concentrated more over the inner shelf than in the Upwelling Season, particularly evident from Point Reyes to Monterey, as well as San Luis Obispo Bay.

During the Davidson Current Season (DCS), virtually the entire continental shelf from Point Reyes to Point Sur exhibited high marine bird biomass.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

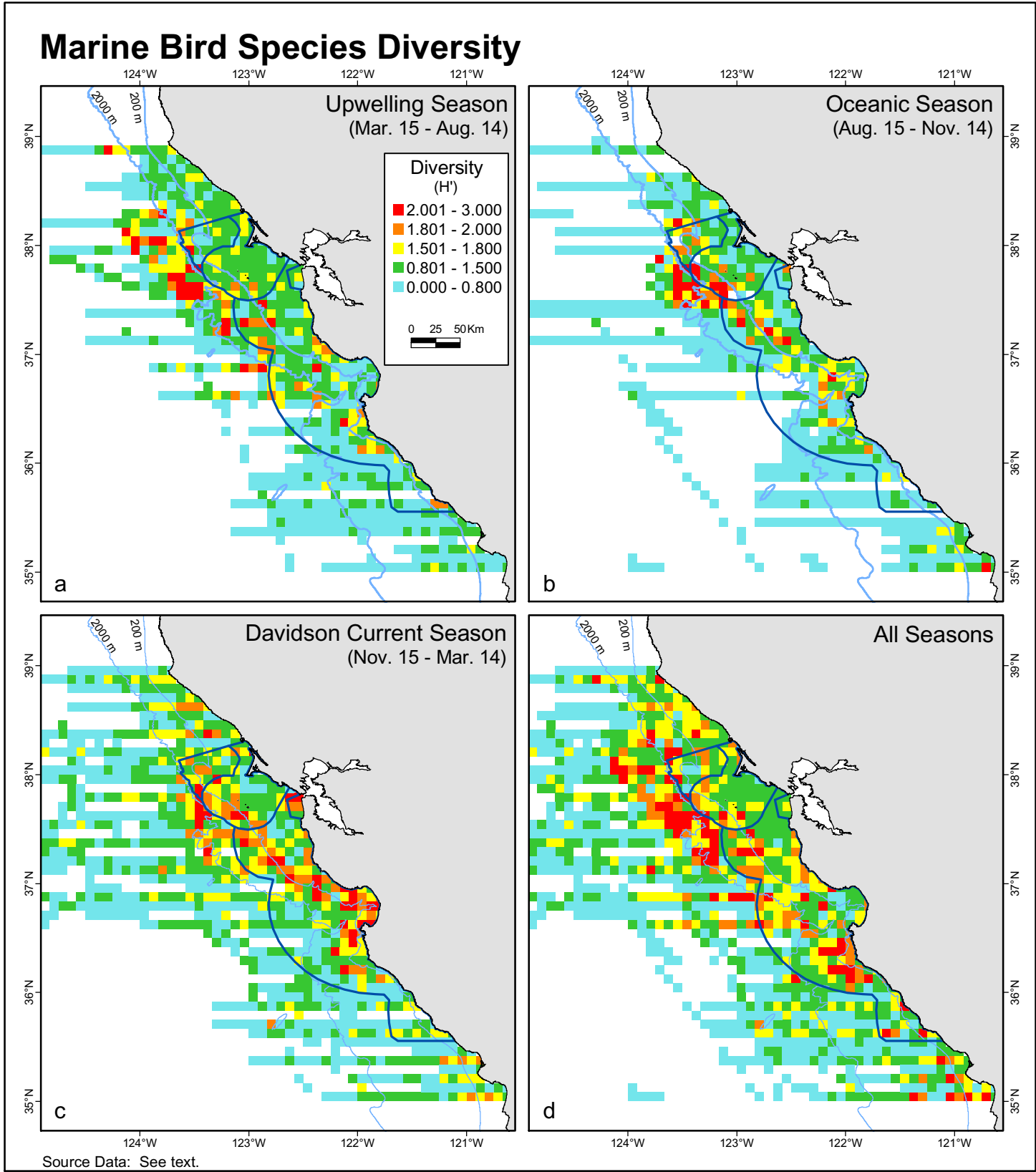


Figure 54. Marine bird diversity, by season and for all seasons.

ABOUT THESE MAPS

Species diversity was calculated for each five minute latitude by five minute longitude cell using density as the variable in the Shannon [Diversity] Index (Shannon and Weaver 1949). This index measures the degree to which a species assemblage is dominated by a few species. If a cell contains high densities of a few species and low densities of all others, the value of diversity (H') will be low, indicating low diversity. Alternatively, if many species are present at similar densities, the value will be high, indicating high diversity. Figures 54a, b, and c show the diversity index H' in three oceanographic seasons; map d shows diversity for all seasons and years combined. Although a density-based calculation of the Shannon Index is less influenced by differences in effort as compared with the index calculated using species counts, a significant correlation ($p < 0.001$) remained between diversity and effort.

To standardize for variable effort among cells and variable strip width among species, density was used for each species in each cell as the basis for calculating the diversity index value. All 76 marine bird species that had been recorded in the data set were included. Cells are colored based on the value of H' computed for a particular season. Red indicates high diversity, blue indicates low diversity. Unsurveyed areas are colored white. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200 meter and 2,000 meter isobaths are also shown in blue.

DATA SOURCES

At-sea densities are based on data from eight survey programs conducted in 1980-2001, which were combined using CDAS software into an MMS-CDAS data set (MMS, 2001) developed for Minerals Management Service and expanded for this project. Of the data sets on the original CD-ROM, four aerial survey data sets provided data in the study area from Point Arena to Point Sal. Of these, one program was still ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis. See section introduction for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDF&G-OSPR), unpublished data. Early data were collected using methods described by Briggs et al. (1987b); more recent data were collected using updated technology but the same general method. Data sources for ship-based survey data include David Ainley and Caol Keiper (unpublished data; see Oedekoven et al., 2001 for details on methods). Although the at-sea data span the years 1980-2001, data are not available for all seasons in all years. For the

Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991 and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources" above). Observation and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells. The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of marine birds seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was censused more than once, densities were averaged, with adjustment made for effort.

The Shannon Index (Shannon and Weaver 1949) was used to quantify species diversity. For each cell, diversity was calculated using the formula

$$H' = - \sum_{i=1}^S \left[\left(\frac{n_i}{n} \right) \ln \left(\frac{n_i}{n} \right) \right]$$

where n_i is the density of species in that cell. Density was used for calculating the index value in order to compensate for variable effort among cells and species. We looked at three oceanographic seasons and at all seasons combined.

The Shannon Index was selected as the diversity metric because it is widely used and accepted in community ecology. It has three desirable properties for a diversity index, noted below. Most diversity indices do not take these three qualities into account. For more information on diversity indices, see Ecological Diversity, E.C. Pielou, pp 7-18.

1. The diversity index is greatest when all species in the community are equally represented in numbers (e.g., evenness in a community). Or, for a given number of species (e.g., richness value), the diversity index should have its greatest value when the proportion of each species is the same.
2. Given two completely diverse or similar communities, the one with the higher number of species has a greater diversity value.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

3. The last property is difficult to summarize but is something like this: This property takes into account the hierarchical nature, or representativeness in the biological classification of each species, when estimating diversity.

RESULTS AND DISCUSSION

Looking first at a summary of all seasons, the marine avifauna was most diverse in areas largely outside of National Marine Sanctuary boundaries, especially in areas of the continental slope and particularly the Farallon Escarpment. Localized areas of high diversity occurring within sanctuary boundaries include: Pioneer, Ascension/Cabrillo, and Carmel canyons, as well as the continental slope off Point Sur.

During the Upwelling Season, the avifauna was the least diverse; areas of highest diversity in this season included the Farallon Escarpment, and Pioneer, Ascension, and Carmel canyons.

During the Oceanic Season, diversity was comparable to that of the Upwelling Season in general. Areas of high diversity continued to include the Farallon Escarpment area, Pioneer Canyon, and inner Monterey Bay Canyon.

During the Davidson Current Season, marine bird diversity, in general, was the highest of the year. Areas of high diversity were all localized, and most occurred over the continental slope (e.g., Farallon Escarpment, and Pioneer, Ascension, Monterey Bay and Carmel canyons) but some also occurred over the shelf (e.g., the inner San Francisco Bay tidal plume and inner portions of Monterey Bay).

However, because of the significant correlation between diversity and effort, some of the diversity patterns may be influenced by differences in effort across the study area. See the additional analysis and discussion of diversity in the Integration section.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

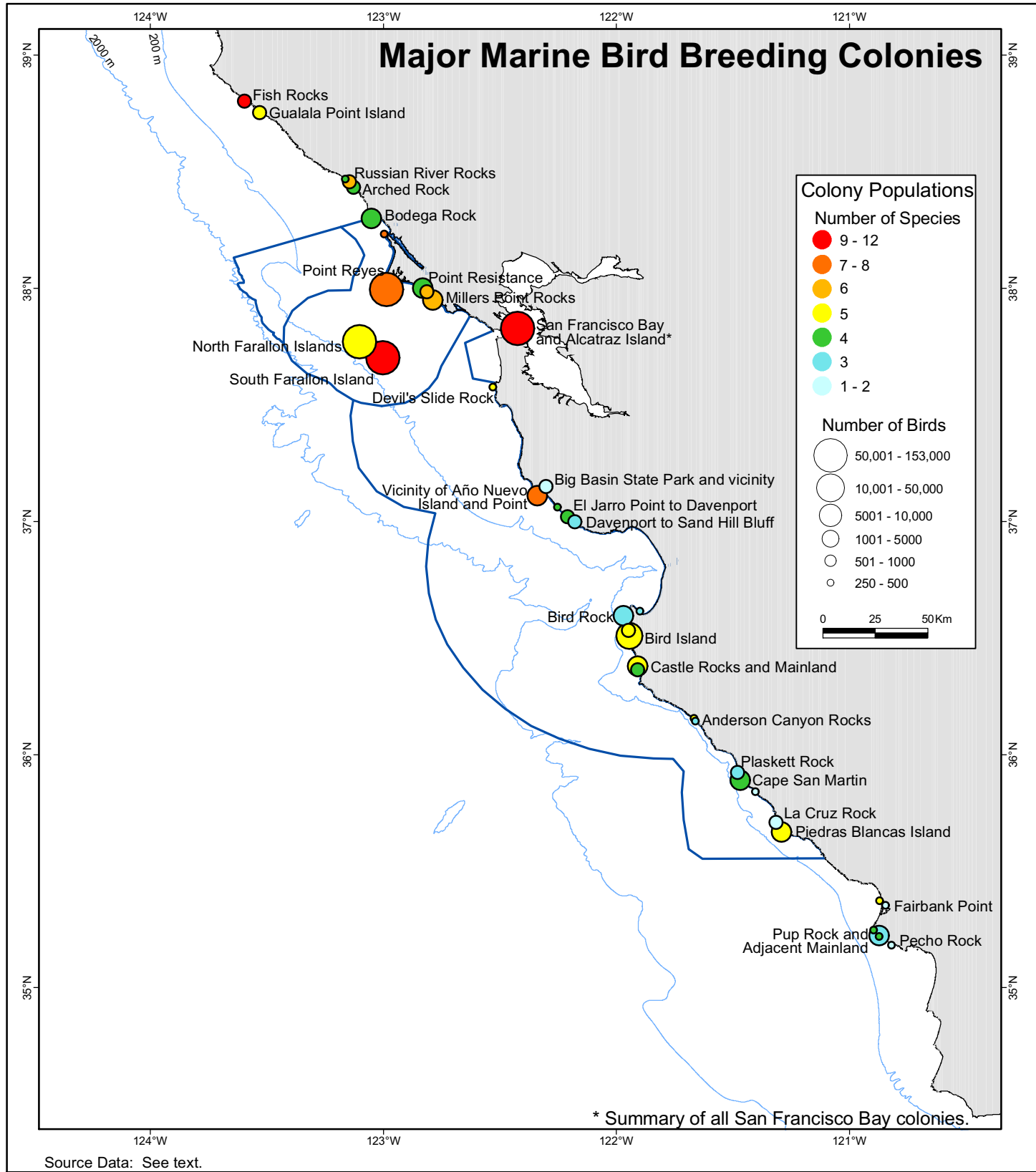


Figure 55. Major marine bird breeding colonies.

ABOUT THIS MAP

The 40 largest marine bird breeding colonies in the study area were chosen for this map (Figure 55). The total number of breeding marine bird species is indicated by the size of the circle, and the number of species using a particular colony is indicated by the circle color. The large symbol at the San Francisco Bay entrance represents a summary of all the colonies in San Francisco Bay. See Table 18 for more information on these colonies.

DATA SOURCES

Data on marine bird colonies were derived primarily from Breeding Populations of Seabirds in California, 1989-1991 (Carter et al., 1992, unpublished data). Colony data were updated where more current information was available. Updated information is presented for some species on South Farallon Island (Sydeman et al., 1998, Warzybok et al., 2002), Año Nuevo Island (Thayer and Sydeman 2002 a, b), Bird Rock, Point Reyes, and Double Point Rocks (Whitworth et al., 2002), Big Basin State Park and vicinity (Laird Henkel, pers. comm) and Devil's Slide Rock (Gerry McChesney, USFWS, pers. comm).

METHODS

Colony locations were plotted using latitude and longitude coordinates from Breeding Populations of Seabirds in California, 1989-1991 (Carter et al., 1992, unpublished data).

RESULTS AND DISCUSSION

The study area is in a geologic subduction zone of the eastern Pacific and adjacent continental margin. Therefore, as with analogous regions elsewhere on the globe (e.g., west coasts of South America and Africa), islands are not common. In somewhat of a departure from this pattern, the Gulf of the Farallones contains far more coastal rocks and offshore islands than anywhere else in the study area and, in fact, this is the case for 400 miles to the north and south. Obvious in this map is the importance to breeding marine birds of the Gulf of the Farallones, defined as the broad shelf from Point Reyes/Tomales Point to Año Nuevo and out to the Farallon Islands. A disproportionate number of breeding colonies and, certainly, most of various species' regional breeding populations, occur here. These colonies are large and diverse owing to the high productivity of surrounding waters and the complexity of habitats in the region. See Table 18 for a numerical summary of each colony's contribution to the breeding marine avifauna of the study area, composed of 16 species, 12 of which breed within the Gulf of the Farallones.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

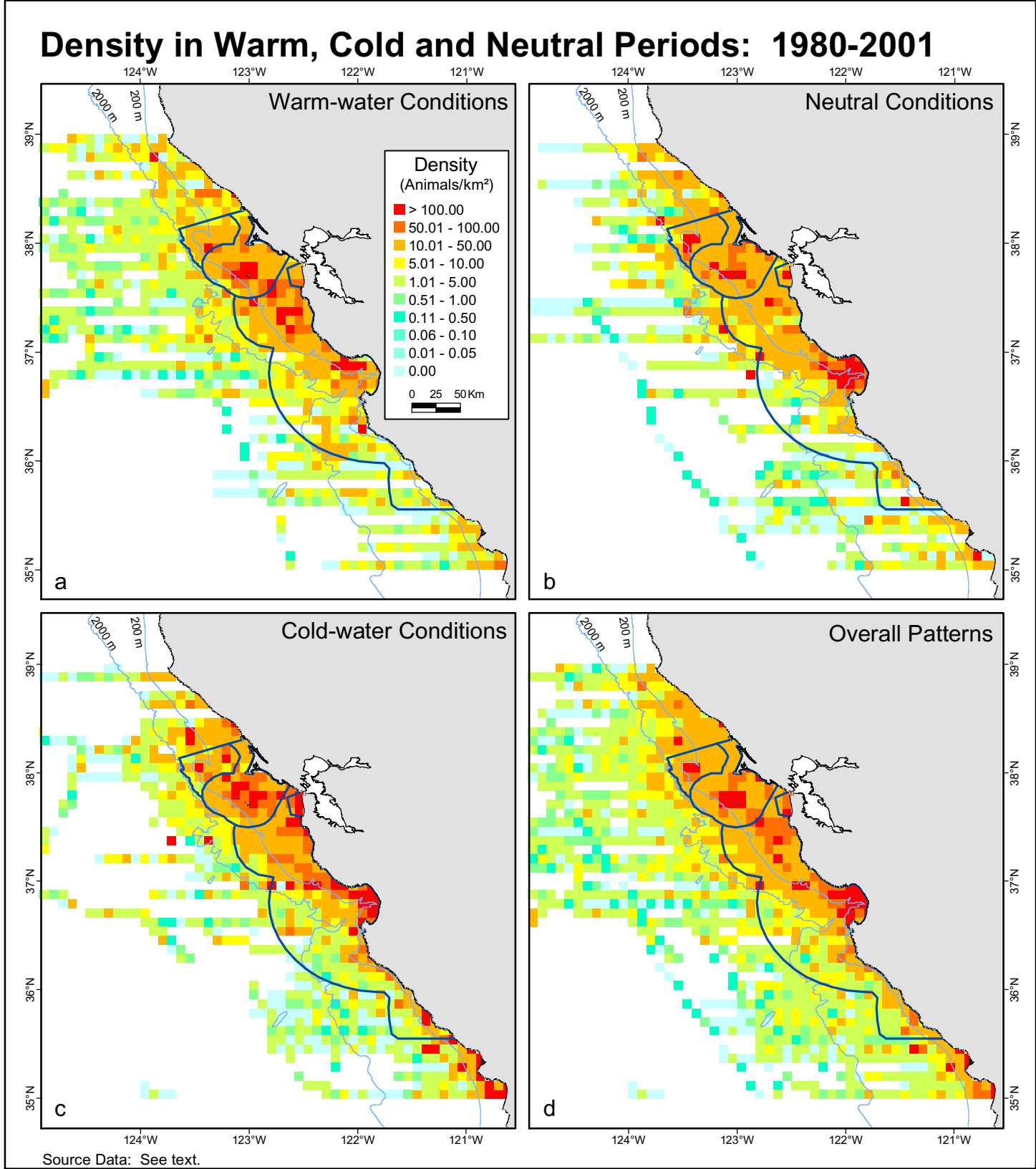


Figure 56. Density in warm, cold, and neutral periods: 1980-2001.

ABOUT THESE MAPS

A comparison of the abundance and distribution of 76 marine birds during warm-water periods (including El Niño), cold-water periods (La Niña) and normal (neutral) periods is provided here as an example of how marine birds may respond to short-term variation in marine climate. In this synthesis, what is shown is density, which treats all species equally regardless of body size. Therefore, the patterns demonstrated by tiny, more abundant species, such as storm-petrels and phalaropes, are more greatly expressed. For a description of how these periods were chosen, see the following topic in the bird section: "Response to Variation in Marine Climate" (pages 49-50).

Figures 56a, b and c show the combined density (birds/km²) of 76 species of marine birds in cold-water, neutral, and warm-water periods, displayed in five minute latitude by five minute longitude cells. Map d shows overall patterns of density. Densities are based on combined data of several studies (see "Methods" and "Data Sources" below). The color and mapping intervals were customized to show the most structure and highlight significant areas. Cells that were surveyed but in which no birds were observed have a density of zero; unsurveyed areas are white. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200 meter and 2,000 meter isobaths are also shown in blue.

DATA SOURCES

At-sea densities are based on data from eight survey programs conducted in 1980-2001; these data sets were combined using CDAS software into an MMS-CDAS data set (MMS, 2001) and expanded for this project. Of the data sets on the original CD-ROM, four aerial survey data sets provided data in the study area from Point Arena to Point Sal. Of these, one program was still ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis. See section introduction for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (MMS, 2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDF&G-OSPR), unpublished data. Early data were collected using methods described by Briggs et al. (1983); more recent data were collected using updated technology but the same general method. Data sources for ship-based survey data include David Ainley and Carol Keiper (unpublished data; see Oedekoven et al., 2001 for details on methods). Although the at-sea data span the years 1980-2001, data are not available for all seasons in all years.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources" above). Observation and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells. The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of marine birds seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was censused more than once, densities were averaged, with adjustment made for effort.

Marine bird density data was then organized into periods where surface ocean conditions were warm (including El Niños), cold (including La Niñas) or neither (neutral). The density of all species seen within respective cells was summed for that cell.

To illustrate these temperature conditions, a comparison of marine bird densities was made by making maps that use selected season/year periods that represented these cold, warm and neutral periods. The data for each "condition" map was grouped as shown below; these groupings were based on the assignments made in Table 14. Once the selection of data were made for each analysis period (i.e., warm, neutral or cold), the density of all birds seen within each cell was summed for that cell.

For the warm-water conditions (including El Niños) map, the following seasons and years were used: Davidson Current Season: 1981, 1983, 1984, 1992, 1993, 1994, 1996, 1998. Upwelling Season: 1985, 1987, 1992, 1993, 1995, 1998. Oceanic Season: 1983, 1997.

For the neutral conditions map, the following seasons and years were used: Davidson Current Season: 1982, 1986, 1995, 1997. Upwelling Season: 1980, 1982, 1986, 1988, 1989, 1994, 1996, 1997. Oceanic Season: 1982, 1991, 1995.

For the cold-water conditions (including La Niñas) map, the following seasons and years were used: Davidson Current Season: 1985, 1991, 1999, 2000, 2001, 2002. Upwelling Season: 1981, 1990, 1991, 1999, 2000, 2001. Oceanic Season: 1980, 1981, 1994, 1996, 1998, 1999, 2000, 2001.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

RESULTS AND DISCUSSION

There was not a great deal of difference in density apparent in the exhibited patterns for the different periods. Nevertheless, during warm-water conditions (e.g., El Niño events) marine bird populations appear to contract more into the area defined by the boundaries of the central California National Marine Sanctuaries, from Tomales Point south to Monterey. Generally, this area contains most of the shelf habitat of the study area, which tends to have a greater complexity of microhabitats than deeper waters. The reason there was not much of an apparent pattern or major difference seen in these maps, is that individual species respond differently to the three different temperature conditions shown. For instance, some may move out of an area but others may move in, and therefore, when species are combined, these individual responses are homogenized.

During both warm and cold excursion from ‘normal’/neutral marine climate, populations seemed to be slightly more widespread, with major concentrations in Monterey Bay. During cold-water conditions (e.g., La Niña events), densities appeared to be the highest, especially in waters close to the coast (e.g., see contiguous high-density, red and orange cells along the coast). During warm-water events, the concentrations are further offshore in the mid to outer shelf and there are fewer highest density (red) cells.

As noted earlier, overall marine bird density in this analysis is generally dominated by two numerically dominant species, common murre and sooty shearwater, and to a lesser degree, by the species identified as abundant in the study area (see Table 15).

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

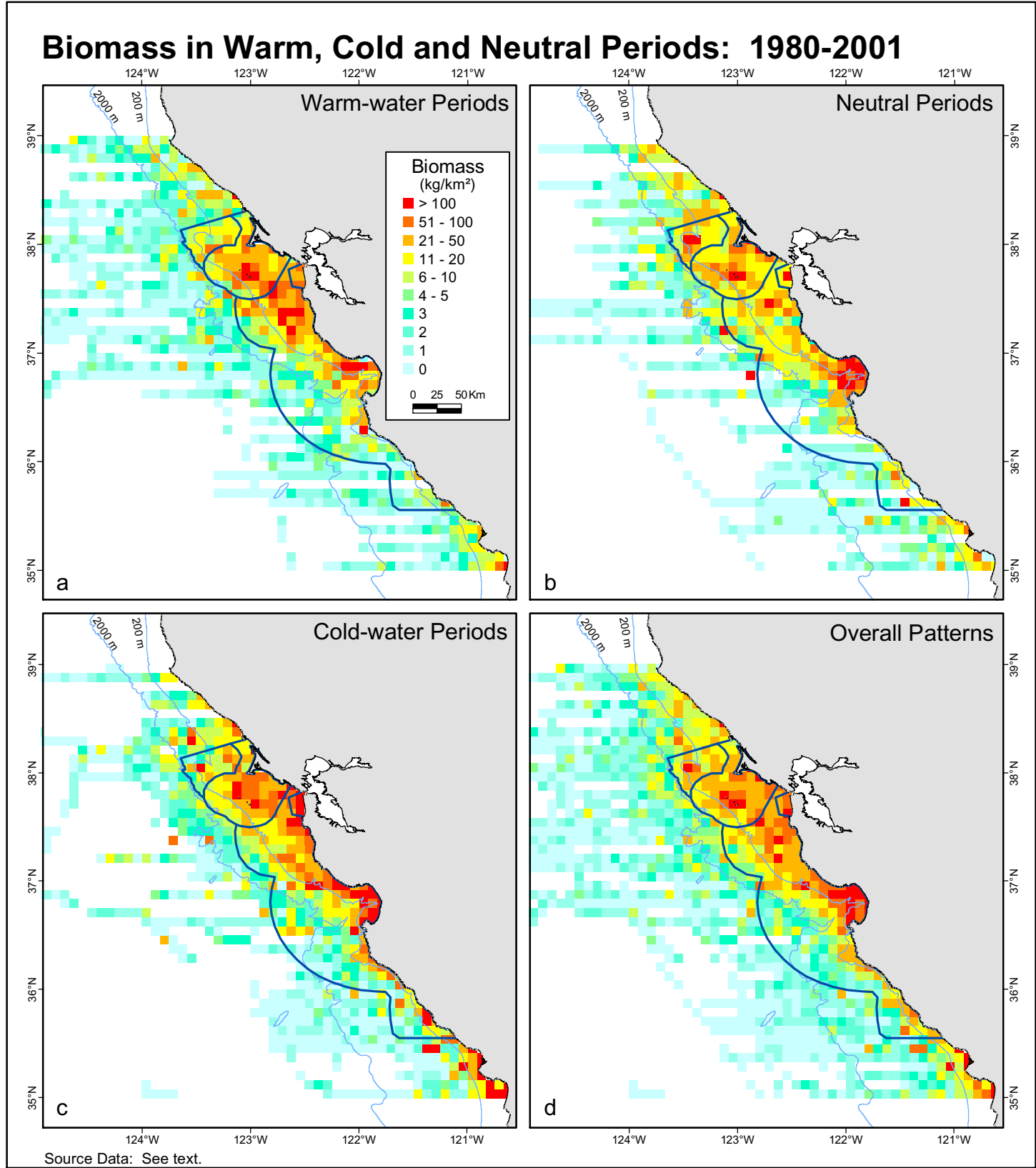


Figure 57. Biomass in warm, cold and neutral periods: 1980-2001.

ABOUT THESE MAPS

A comparison of the abundance and distribution of 76 marine birds during warm-water (El Niño) compared to cold-water (La Niña) and normal (neutral) periods provides an example of how marine birds respond to short-term excursions from the usual marine climate. In this comparison, densities were converted to biomass by multiplying density by body mass of each species. This comparison, thus, emphasizes more the larger-bodied species, such as Sooty Shearwater and Common Murre.

Figures 57a, b, and c show the combined biomass density (kg/km²) of 76 species of marine birds in cold-water, neutral, and warm-water periods, displayed in five minute latitude by five minute longitude cells. Map d shows overall patterns of biomass density. Densities are based on combined data of several studies (see “Methods” and “Data Sources” below). The color and mapping intervals were customized to show the most structure and highlight significant areas. Cells that were surveyed but in which no birds were observed have a density of zero; unsurveyed areas are white. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200 meter and 2,000 meter isobaths are also shown in blue.

DATA SOURCES

At-sea densities are based on data from eight survey programs conducted in 1980-2001. These data were combined using CDAS software into an MMS-CDAS data system (MMS, 2001) for the Minerals Management Service and expanded for this project. Of the data sets on the original MMS-CDAS CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, one program was still ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis. See section introduction for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (MMS, 2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDF&G-OSPR), unpublished data. Early data were collected using methods described by Briggs et al. (1987b); more recent data were collected using updated technology but the same general method. Data sources for ship-based survey data include David Ainley and Carol Kieper (unpublished data; see Oedekoven et al., 2001 for details on methods). Although the at-sea data span the years 1980-2001, data are not available for all seasons in all years.

Data on average mass for each species were derived from *Body Weights of 686 Species of North American Birds* (Dunning 1993). In a few instances, a species was not listed in this

reference; in these cases, the mass of a closely related bird of a similar size was used.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see “Data Sources” above). Observation and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells. The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of marine birds seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was censused more than once, densities were averaged, with adjustment made for effort.

For each species that occurred in a cell, the average density was then multiplied by a species’ body mass (from Dunning, 1993). This resulted in an estimate of biomass for that species. The biomass of all species in each cell was summed to give the cell biomass.

Marine bird density data was then organized into periods where surface ocean conditions were warm (including El Niños), cold (including La Niñas) or neither (neutral). The density of all species seen within respective cells was summed for that cell.

To illustrate these temperature conditions, a comparison of marine bird densities was made by making maps that use selected season/year periods that represented these cold, warm and neutral periods. The data for each condition map was grouped as shown below; these groupings were based on the assignments made in Table 14. Once the selection of data were made for each analysis period (i.e., warm, neutral or cold), the density of all birds seen within each cell was summed for that cell.

For the warm-water conditions (including El Niños) map, the following seasons and years were used: Davidson Current Season: 1981, 1983, 1984, 1992, 1993, 1994, 1996, 1998. Upwelling Season: 1985, 1987, 1992, 1993, 1995, 1998. Oceanic Season: 1983, 1997.

For the neutral conditions map, the following seasons and years were used: Davidson Current Season: 1982, 1986, 1995, 1997.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

Upwelling Season: 1980, 1982, 1986, 1988, 1989, 1994, 1996, 1997. Oceanic Season: 1982, 1991, 1995.

For the cold-water conditions (including La Niñas) map, the following seasons and years were used: Davidson Current Season: 1985, 1991, 1999, 2000, 2001, 2002. Upwelling Season: 1981, 1990, 1991, 1999, 2000, 2001. Oceanic Season: 1980, 1981, 1994, 1996, 1998, 1999, 2000, 2001.

RESULTS AND DISCUSSION

There was slightly more difference in biomass than was observed for the analogous comparison of density. Biomass was generally more concentrated during warm and cold conditions than during neutral conditions, especially cold-water periods, which were mimicked by the overall all-conditions summary. Many inner shelf habitat areas exhibited high marine bird biomass during cold-water periods. The Farallon Ridge and Monterey Bay had relatively high biomass under all conditions.

As noted earlier, marine bird biomass in this analysis is generally dominated by two, relatively heavy-bodied, numerically dominant species: common murre and sooty shearwater, and to a lesser degree, by the species identified as abundant in the study area (see Table 15).

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

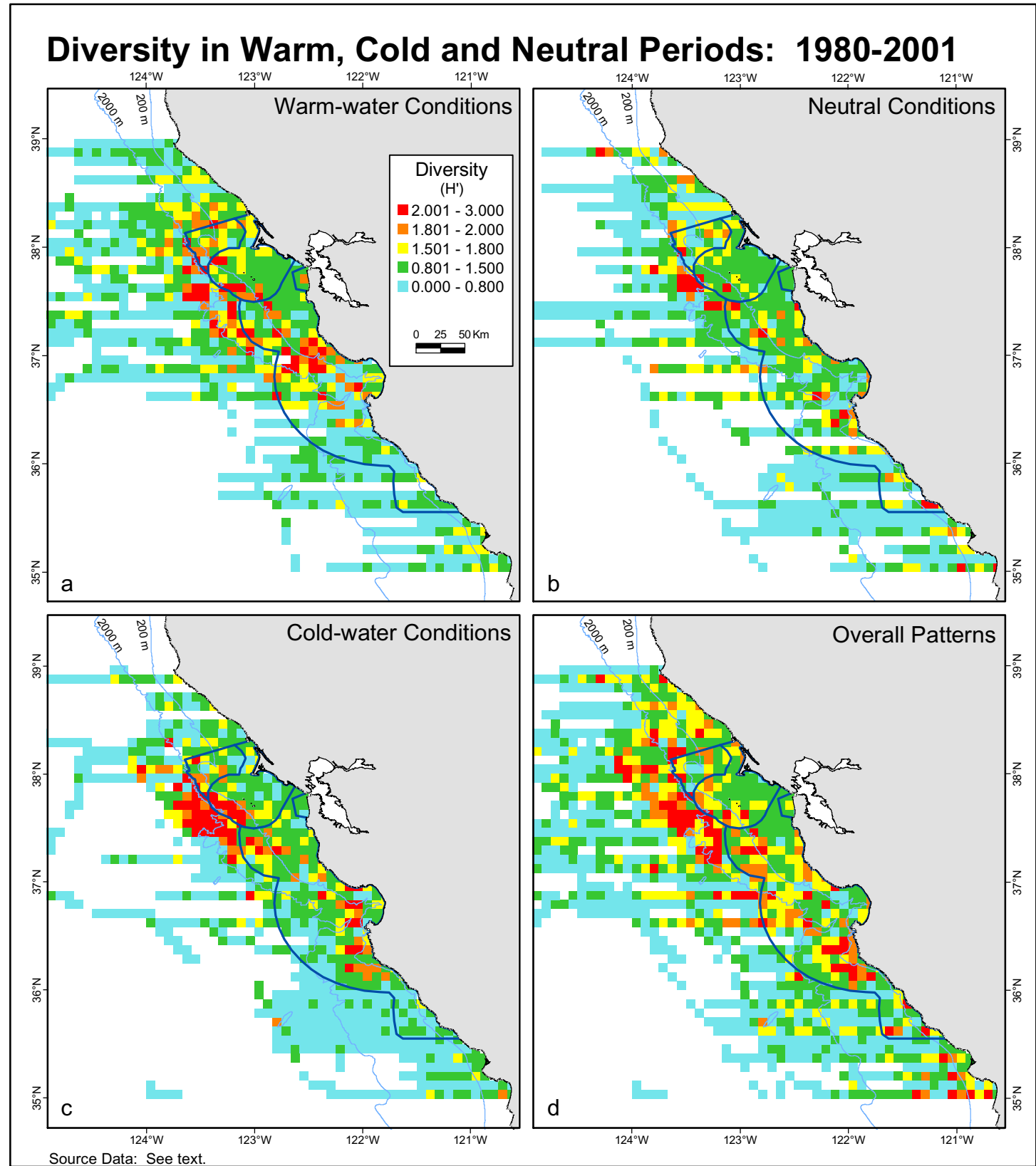


Figure 58. Diversity in warm, cold and neutral periods: 1980-2001.

ABOUT THESE MAPS

A comparison of the abundance and distribution of marine birds during warm-water periods (e.g., El Niño events), cold-water periods (e.g., La Niña events) and normal (neutral) periods provides an example of how marine birds may respond to short-term excursions from the usual marine climate. These maps (Figure 58) show species diversity, calculated for each five minute latitude by five minute longitude cell using density as the variable in the Shannon [Diversity] Index (Shannon and Weaver 1949); all 76 marine bird species that had been recorded in the data set were included.

The Shannon Index measures the degree to which a species assemblage is dominated by a few species. If a cell contains high densities of a few species and low densities of all others, the value of H' will be low, indicating low diversity. Alternatively, if many species are present at similar densities, the value will be high, indicating high diversity. Maps a, b and c show the diversity index H' in cold-water, neutral, and warm-water periods; map d shows overall patterns. Cells are colored based on the value of H' computed for a particular season. Red indicates high diversity, blue indicates low diversity. Although there was a significant correlation between diversity and effort, the observed patterns of bird diversity are robust and were largely unchanged by methods designed to correct for effort.

Unsurveyed areas are white. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200 meter and 2,000 meter isobaths are also shown in blue.

DATA SOURCES

At-sea densities are based on data from eight survey programs conducted in 1980-2001, which were combined using software developed for MMS-CDAS (MMS, 2001) and expanded for this project. Of the data sets on the original MMS-CDAS CD-ROM, four aerial survey data sets provided data in the study area from Point Arena to Point Sal. Of these, one program was still ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis. See section introduction for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (MMS, 2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDF&G-OSPR), unpublished data. Early data were collected using methods described by Briggs et al. (1983); more recent data were collected using updated technology but the same general method. Data sources for ship-based survey data include David Ainley and Carol Keiper (unpublished data; see Oedekoven et al., 2001 for

details on methods). Although the at-sea data span the years 1980-2001, data are not available for all seasons in all years.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources" above). Observation and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells. The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of marine birds seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was censused more than once, densities were averaged, with adjustment made for effort.

The Shannon Index (Shannon and Weaver 1949) was used to quantify species diversity.

$$H' = - \sum_{i=1}^S \left[\left(\frac{n_i}{n} \right) \ln \left(\frac{n_i}{n} \right) \right]$$

This index measures the degree to which the species assemblage is dominated by a single species. If species A dominates all the species seen within a cell, then diversity is low; and vice versa. To standardize for variable effort among cells and variable strip width among species, we used the density for each species in each cell as the basis for calculating the index value.

Marine bird density data was then organized into periods where surface ocean conditions were warm (including El Niños), cold (including La Niñas) or neither (neutral). The diversity of all species seen within respective cells was determined for that cell.

To illustrate these temperature conditions, a comparison of marine bird densities was made by making maps that use selected season/year periods that represented these cold, warm and neutral periods. The data for each condition map was grouped as shown below; these groupings were based on the assignments made in Table 14. Once the selection of data were made for each analysis period (i.e., warm, neutral or cold), the density of all birds seen within each cell was summed for that cell.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

For the warm-water conditions (Including El Niños) map, the following seasons and years were used: Davidson Current Season: 1981, 1983, 1984, 1992, 1993, 1994, 1996, 1998. Upwelling Season: 1985, 1987, 1992, 1993, 1995, 1998. Oceanic Season: 1983, 1997.

For the neutral conditions map, the following seasons and years were used: Davidson Current Season: 1982, 1986, 1995, 1997. Upwelling Season: 1980, 1982, 1986, 1988, 1989, 1994, 1996, 1997. Oceanic Season: 1982, 1991, 1995.

For the cold-water conditions (Including La Niñas) map, the following seasons and years were used: Davidson Current Season: 1985, 1991, 1999, 2000, 2001, 2002. Upwelling Season: 1981, 1990, 1991, 1999, 2000, 2001. Oceanic Season: 1980, 1981, 1994, 1996, 1998, 1999, 2000, 2001.

RESULTS AND DISCUSSION

Under all variations of climate, marine bird diversity was highest over the continental slope, with the Farallon Escarpment and Pioneer Canyon, in particular, standing out. Of lesser importance was outer Monterey Bay Canyon and Point Sur slope. Areas of high diversity were more spread out along the slope when ocean temperatures were warm. Adding to the latter hot spots was the area around Ascension Canyon. During neutral conditions, diversity everywhere was relatively low, when compared with higher diversities during the warm-water and cold-water periods.

Although there was a significant correlation between diversity and effort, the observed patterns of bird diversity are robust and were largely unchanged by methods designed to correct for effort.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

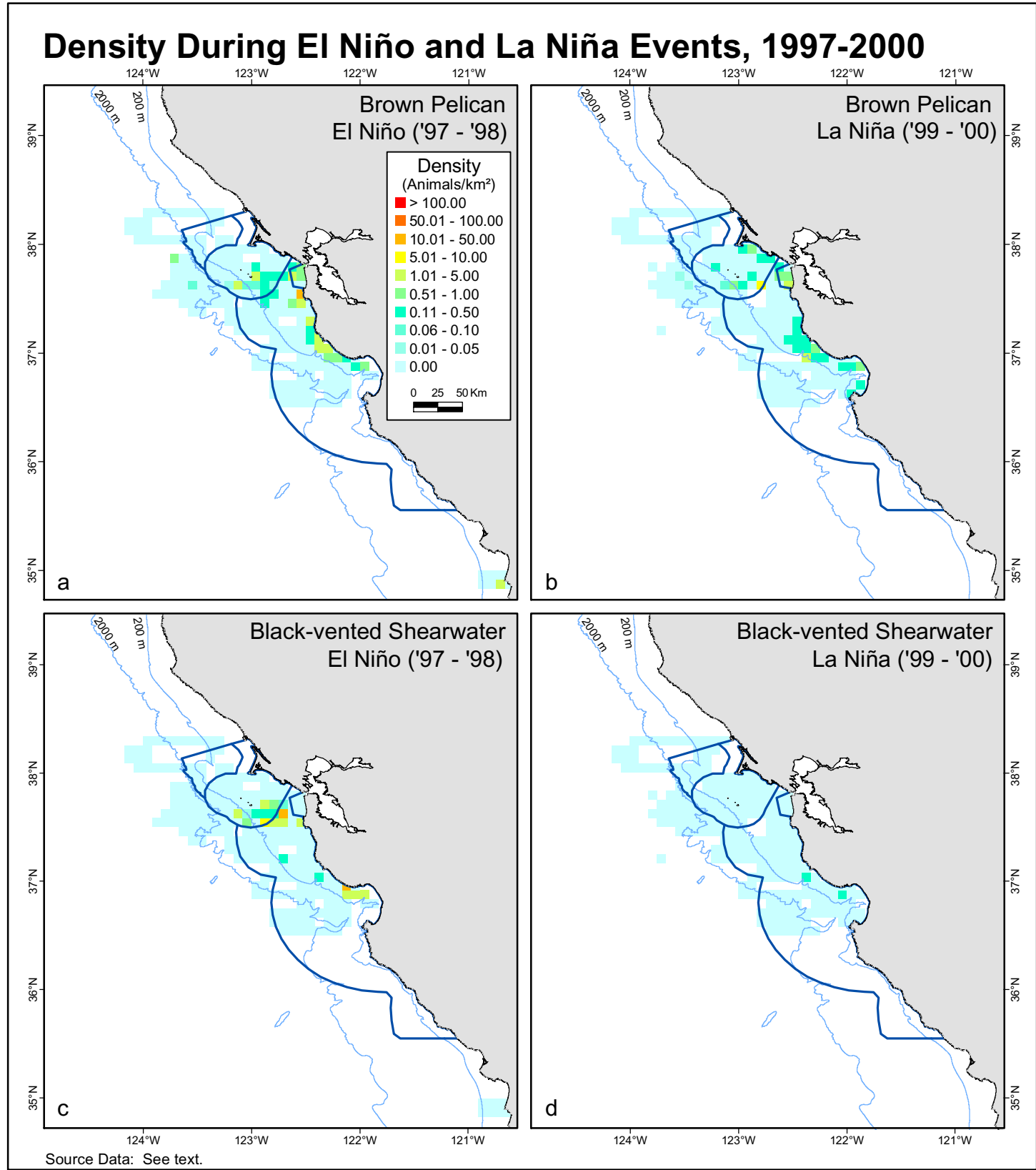


Figure 59. Density during El Niño and La Niña events, 1997-2000.

ABOUT THESE MAPS

A comparison of the density and distribution for two species during an intense El Niño (1997-98) and an adjacent and intense La Niña (1999-00) provides an example of how marine birds respond to short-term anomalies of marine climate (Figure 59). In this comparison, the responses of individual species do not cancel out the effects of another, as was the case in comparisons when measures of overall abundance were used (Figures 52, 53, 56 and 57).

Densities are based on combined data of several studies (see “Methods” and “Data Sources” below). The color and mapping intervals were customized to show the most structure and highlight significant areas. Cells that were surveyed but in which no birds were observed have a density of zero; unsurveyed areas are white. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200 meter and 2,000 meter isobaths are also shown in blue.

DATA SOURCES

At-sea densities are based on data from eight survey programs conducted in 1980-2001. These data were combined using CDAS software into an MMS-CDAS data system (MMS, 2001) for the Minerals Management Service and expanded for this project. Of the data sets on the original MMS-CDAS CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, one program was still ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis. See section introduction for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDF&G-OSPR), unpublished data. Early data were collected using methods described by Briggs et al. (1983); more recent data were collected using updated technology but the same general method. Data sources for ship-based survey data include David Ainley and Carol Keiper (unpublished data; see Oedekoven et al., 2001 for details on methods). Although the at-sea data span the years 1980-2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991 and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see “Data Sources” above).

Observation and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of marine birds seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was censused more than once, densities were averaged, with adjustment made for effort.

The most intense events were selected for this comparison, as well as events that occurred very close in time. In that way, long-term changes in populations were not involved in the species’ occurrence patterns. For El Niño, data were used from the Oceanic Season 1997 through Upwelling Season 1998; for La Niña the data were from the Oceanic Season 1998 through Oceanic Season 1999; see Table 14.

RESULTS AND DISCUSSION

During intense warm periods, species such as brown pelican, black storm-petrel and black-vented shearwater, which zoo-geographically are centered to the south of central California (where waters are normally warmer and food availability relatively lower), move into central California waters when warmer ocean temperatures expand northward. Many of these individuals have foregone breeding owing to depleted food availability, which is often more extreme in areas to the south where these species breed. Shown here are comparisons for brown pelican and black-vented shearwater. In both cases, densities are much higher in central California during warm-water periods. In fact, during these conditions brown pelicans expand as far north as the Columbia River and even farther; black-vented shearwaters, however, don’t go much farther than central California waters.

The response of species to short-term cold-water conditions (La Niña) is far less dramatic and, in fact, no examples could be found to clearly illustrate this. This is due to many factors, perhaps the most important being that the geographic affinity of central California marine birds is largely ‘subarctic’ and therefore, the central California avifauna is at the southern extreme of its range. As a result, there is little reason for northern species to shift into the area when the latter becomes slightly colder. The other main reason for lack of examples illustrating response to cold conditions is that a major regime shift coincided with the best example, i.e. intense La Niña conditions in 1999-00 (see Figure 60). Therefore, it is difficult to separate the factors responsible in the avifaunal shifts observed.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

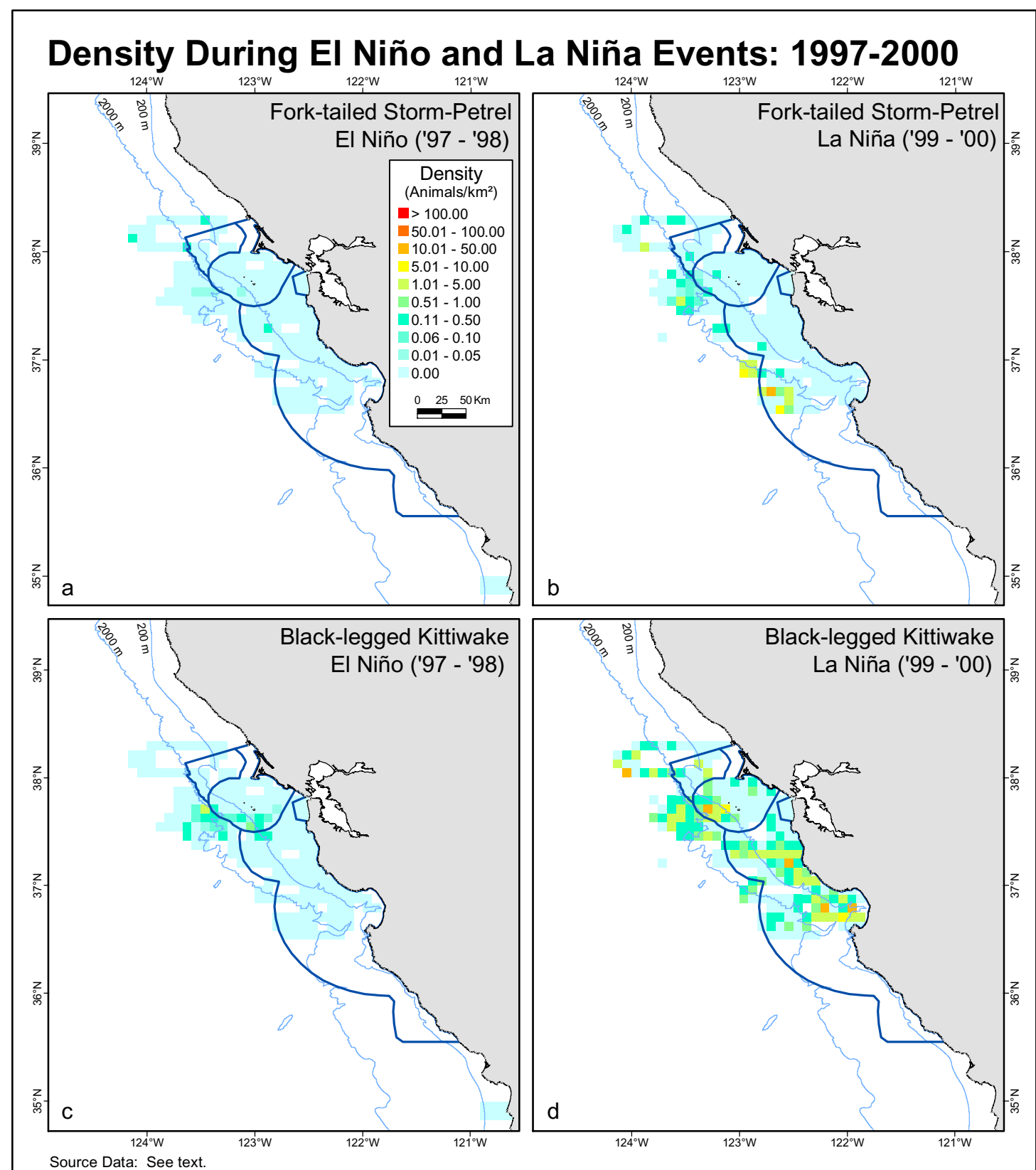


Figure 60. El Niño/La Niña Event changes, as an example of regime shift effects.

ABOUT THESE MAPS

A comparison of the abundance and distribution of two species during intense El Niño events compared to La Niña events provides an example of how marine birds may respond to short-term anomalous marine climate. In the case of regime shifts, which involve climate change on a decadal time scale, a shift may have occurred during the study period corresponding also to the switch from intense El Niño (Oceanic Season 1997 - Upwelling Season 1998) to intense La Niña (Oceanic Season 1998 - Oceanic Season 2000). Therefore, at this time, it is difficult to perceive whether the changed bird distributional patterns were short-term or long-term. Subsequently the cold conditions continued, thus indicating a longer-term regime shift (Bogard et al., 2000, Schwing and Moore 2000, Schwing et al. 2002).

Densities are based on combined data of several studies (see Methods and Data Sources below). The color and mapping intervals were customized to show the most structure and highlight significant areas. Cells that were surveyed but in which no birds were observed have a density of zero; unsurveyed areas are white. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200 meter and 2,000 meter isobaths are also shown in blue.

DATA SOURCES

At-sea densities for this analysis are based on a subset of data from the eight survey programs. These data were combined using CDAS software into an MMS-CDAS data system (MMS, 2001) for the Minerals Management Service and expanded for this project. Of the data sets on the original MMS-CDAS CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, one program was still ongoing and data from recent years were added to this data set. In addition, data from four ship-based survey programs were converted to a compatible format for analysis. See section introduction for details on individual data sets. Data collected since 1996 was used for this comparison.

METHODS

At-sea densities for this analysis are the result of a synthesis of subsetting data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see Data Sources above). Observation and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into five minute latitude by five minute longitude cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell

(estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of marine birds seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was censused more than once, densities were averaged, with adjustment made for effort.

Species densities were mapped by grid cells on either side of the regime shift node, Oceanic Season 1997 through Upwelling Season 1998 versus Oceanic Season 1998 through Oceanic Season 2000.

RESULTS AND DISCUSSION

In 1999-2000, the mean state of the California Current System may have moved from a “warm regime”, present since 1976, to a “cold” regime (Schwing et al. 2002). On the other hand, subsequent years of observation may indicate that we only witnessed the transition from one of the strongest El Niños to one of the strongest La Niñas seen in the past 100 years.

Regardless, in response, more northern species such as fork-tailed storm-petrel and black-legged kittiwake, which are present mostly during the Davidson current season, found the cooler, central California waters more to their liking and, rather than avoiding the area as in the 20 previous years of the warm regime, arrived or remained longer to winter in very large numbers. Unfortunately, data during the Oceanic and Davidson current seasons of years since 2000 were not collected.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

SECTION SUMMARY

The following section provides a summary discussion of the marine bird analyses, relative to the study area and the three national marine sanctuaries off north/central California.

Life History and Management Characteristics

The marine avifauna off north/central California, as represented in the summary data set, are composed of 76 marine bird species, with 39 occurring regularly enough to assess and map patterns of their occurrence. Table 15 is a summary of selected life history and management information for 39 of the marine bird species.

Species Relative Abundance in the Study Area. Based on the analysis of the at-sea data and as indicated in Table 15, among the more regularly occurring species, two are very abundant, eight are abundant, 16 are common, 12 are uncommon, and two are rare. Relative abundance was estimated on a logarithmic scale of number of individuals seen within the study area on surveys during the study period. The majority of the species (26) are present only seasonally, but of the 14 species that breed in the study area, 10 are present year round.

Food Types. With regard to trophic relationships, the majority of marine bird species are either zooplanktivores (generally smaller-bodied) and/or piscivores. Major prey items are: euphausiids (*Thysanoessa spinifera* and *Euphausia pacifica*), market squid (*Loligo opalescens*), juvenile rockfish (*Sebastes* spp, especially *Sebastes jordani*), anchovy (*Engraulis mordax*), herring (*Clupea harengus*), smelt (*Atherinops californiensis* and *Spirinchus starksi*), Pacific saury (*Cololabis saira*), sardine (*Sardinops sagax*), midshipman (*Porichthys notatus*), surfperch (several species) and myctophids (several species), with importance varying by the habitat and time of year in which a particular bird species was foraging (Briggs and Chu 1987, Ainley and Boekelheide 1990).

Summary of Spatial and Temporal Patterns in Large and Relatively Smaller Areas

Table 16 is a summary of the temporal and spatial patterns observed for the regularly occurring marine birds of the study area. This summary was developed by visual inspection of the species seasonal density maps and is provided as a simple summary of species distributions and abundance by season and for selected habitat and management features.

It is obvious that large numbers of marine birds occur in the study area year round. The species composition, however,

Table 15. Life history and management information for selected marine birds off north/central California.

Common Name	Scientific Name	Population Status in Study Area			Temporal Occurrence in Study Area			Major Food Items ³					
		Protection Status ¹	Population Trend ⁶	Relative Abundance at Sea ²	Seasonal Occurrence ⁵	Primary Months of Presence ⁵	Months When Breeding ⁵	Plankton	Fish	Cephalopods (squid, octopus)	Euphausiids (krill)	Benthic Invertebrates	Generalist Feeder
Loons/Grebes													
Pacific loon	<i>Gavia pacifica</i>		Unknown	Common	Seasonal	Nov-Apr			x				
Common loon	<i>Gavia immer</i>		Unknown	Uncommon	Seasonal	Nov-Apr			x				
Western & Clark's grebes	<i>Aechmophorus occidentalis</i> , <i>A. clarksii</i>		Unknown	Abundant	Year-round	Nov-Sept	Apr-Sept		x				
Albatrosses/Petrels													
Black-footed albatross	<i>Phoebastria nigripes</i>		Decreasing	Common	Year-round	Mar-Aug				x			x
Laysan's albatross	<i>Phoebastria immutabilis</i>		Unknown	Rare	Seasonal	Nov-Mar				x			x
Northern fulmar	<i>Fulmarus glacialis</i>		Increasing	Common	Seasonal	Nov-Mar							x
Sooty shearwater	<i>Puffinus griseus</i>		Declining	V.Abundant	Seasonal	Apr-Aug		x	x	x	x		
Pink-footed shearwater	<i>Puffinus creatopus</i>		Stable?	Common	Seasonal	Apr-Aug			x	x			
Buller's shearwater	<i>Puffinus bulleri</i>		Unknown	Common	Seasonal	Aug-Nov			x				
Black-vented shearwater	<i>Puffinus opisthomelas</i>		Stable?	Uncommon	Seasonal	Aug-Nov		x?					
Leach's storm-petrel	<i>Oceanodroma leucorhoa</i>		Unknown	Common	Seasonal	March-Sept	April-Sept	x			x		x
Ashy storm-petrel	<i>Oceanodroma homochroa</i>	SSC	Increasing	Common	Year-round	All	Feb-Oct	x			x		x
Fork-tailed storm-petrel	<i>Oceanodroma furcata</i>		Decreasing?	Uncommon	Seasonal	Nov-Mar		x			x		x
Black storm-petrel	<i>Oceanodroma melania</i>	SSC	Unknown	Uncommon	Seasonal	Nov-Mar		x					x
Sea Ducks (Scoters)													
Surf scoter	<i>Mellanita perspicillata</i>		Stable	Abundant	Seasonal	Nov-Apr							x
Pelican/Cormorants													
California brown pelican	<i>Pelecanus occidentalis californicus</i>	FE, SE	Increasing	Common	Seasonal	Aug-Nov			x				
Pelagic cormorant	<i>Phalacrocorax pelagicus</i>		Stable?	Uncommon	Year-round	All	Apr-Sept	x	x	x			x
Brant's cormorant	<i>Phalacrocorax pennicilatus</i>		Stable?	Abundant	Year-round	All	Apr-Sept		x				
Double-crested cormorant	<i>Phalacrocorax auritus</i>		Increasing?	Uncommon	Year-round	All	Mar-Aug		x				
Phalaropes													
Red phalarope	<i>Phalaropus fulicaria</i>		Stable?	Common	Seasonal	Mar-Aug		x			x		x
Red-necked phalarope	<i>Phalaropus lobatus</i>		Stable?	Common	Seasonal	Mar-Aug		x			x		x
Gulls/Terns													
Western gull	<i>Larus occidentalis</i>		Declining	Abundant	Year-round	All	Apr-Aug				x		x
California gull	<i>Larus californicus</i>		Increasing	Abundant	Seasonal	Nov-Mar							x
Glaucous-winged gull	<i>Larus glaucescens</i>		Stable	Uncommon	Seasonal	Nov-Mar							x
Heermann's gull	<i>Larus heermanni</i>		Stable?	Common	Year-round	Aug-Nov			x				
Sabine's gull	<i>Xerna sabini</i>		Stable	Common	Seasonal	Mar-Aug		x			x		
Black-legged kittiwake	<i>Rissa tridactyla</i>		Increasing	Common	Seasonal	Nov-Mar			x				
Caspian tern	<i>Sterna caspia</i>	SSC	Stable	Uncommon	Seasonal	Mar-Nov	Apr-Aug		x				
Elegant tern	<i>Sterna elegans</i>		Stable	Uncommon	Seasonal	July?-Nov			x				
Arctic tern	<i>Sterna paradisaea</i>		Stable?	Common	Seasonal	Mar-Nov			x				
Alcids													
Common murre	<i>Uria aalge</i>		Increasing	V.Abundant	Year-round	All	Apr-Aug	x	x	x	x		
Pigeon guillemot	<i>Cepphus columba</i>		Stable?	Uncommon	Seasonal	Mar-Aug	Mar-Aug		x	x			x
Cassin's auklet	<i>Ptychoramphus aleuticus</i>		Decreasing?	Abundant	Year-round	All	Mar-July	x			x		
Marbled murrelet	<i>Synthliboramphus marmoratus</i>	FT, ST	Stable	Uncommon	Year-round	All	Apr-Aug	x	x				
Xantus' murrelet	<i>Synthliboramphus hypoleucus</i>	ST	Unknown	Uncommon	Seasonal	May-July			x				
Craveri's murrelet	<i>Synthliboramphus craveri</i>		Unknown	Rare	Seasonal	May-July			x				
Tufted puffin	<i>Fratercula cirrhata</i>		Decreasing	Uncommon	Seasonal	Mar-Aug	Apr-Aug	x	x				
Rhinoceros auklet	<i>Cerorhinca monocerata</i>		Stable	Abundant	Year-round	Nov-Aug	Apr-Aug	x	x	x	x		

Notes

- Management status categories are as follows: FE–federally endangered; FT–federally threatened; SE–state endangered; ST–state threatened; SSC–state species of special concern.
- Relative abundance estimates are based on the number of individuals tallied in the at-sea survey data, and the categories are defined as follows:
Rare – up to 100 birds; Uncommon – up to 1,000; Common – up to 10,000; Abundant – up to 100,000; and Very Abundant – up to 1,000,000.
- Information on food items are from Ainley & Sanger 1979, Briggs & Chu 1987, and Ainley & Boekelheide 1990.
- Entries with question marks are the principal investigators best estimate.
- Timing information is from Cogswell, 1977 and Ainley and Boekelheide, 1990, except for Caspian tern breeding time, which came from Joelle Buffa, FWS, pers. comm.
- Information on population status was based on analysis of the shipboard data sets, from 1985-2001.
- Months of presence and breeding in the study area are approximations, because timing is strongly influenced by the interannual variability of environmental conditions in the study area.
- Information on population status and temporal occurrence refers only to birds and their activities in the study area.

changes greatly due to the presence of southern hemisphere-breeding species that are ‘wintering’ in large numbers in the study area during the Upwelling Season and subarctic-breeding species ‘wintering’ in large numbers during the Davidson Current Season. Additionally, many migrants pass through the region, but foraging as they go, during the Oceanic and early Upwelling seasons.

In general, the highest concentrations and the greatest variety of marine birds are found over the continental shelf and slope, where there are more microhabitats defined by ocean complexity (depth, currents, tide rips, etc.). A number of smaller, more discrete areas attract marine birds because more food is available; the most important of these are Farallon Escarpment, Farallon Ridge, San Francisco Bay tidal plume, inner Monterey Bay, and Estero/San Luis Obispo bays.

Patterns Observed in Density, Biomass Density and Diversity Across Species

Another way to summarize occurrence patterns of marine birds in the study area is to combine species distribution and abundance data and analyze for the biological metrics of species diversity, biomass and density. Analyses for overall density, biomass and diversity were done with respect to ocean season and to periods of unusual ocean climate (i.e., warm-water, cold-water and neutral periods). For these summary analyses across species, we used the data for 76 marine bird species that were contained in the combined data set.

Overall Density and Biomass. The seasonal and ‘combined-season” densities of 76 marine birds were calculated for each five-minute by five-minute cell as the number of individuals per km². Biomass (kg/km²) was then calculated as the product of density and the mean body mass for each species, taken from Dunning (1993). If a species was not listed in this reference, the body weight of a related species of a similar size was used.

The distribution of marine birds across all taxa is similar for density (Figure 52) and biomass density (Figure 53). This is because the avifauna is dominated (in terms of both number of individuals and their body mass) by the Common Murre and Sooty Shearwater. Therefore, the patterns in sum are close to what is evident individually for these particular dominant species. Accordingly, the major biomass and density areas i.e., the inner and outer shelf, are biased toward these two species.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

Table 16. A summary of temporal and spatial patterns in the at-sea survey data (1980-2001) of selected marine birds off north/central California.

Family Name/ Species Common Name	Seasonal Occurrence			Associations with Large Bathymetrically-Defined Areas					Species Occurs in Study Area, But Mostly Outside Sanctuary Bounds	Associations with Discrete Physiographic/Oceanic Features																
	Upwelling Season (3/15-8/14)	Ocean Season (8/15-11/14)	Davidson Current Season (11/15-3/14)	Coast & Inner Shelf (~0-100m)	Outer Shelf (~100-200m)	Upper Slope (~200-1000m)	Lower Slope (~1000-2000m)	Deep Ocean (beyond 2000m)		Cordell Bank	Bodega Canyon	Fanny Shoal	Farallon Escarpment	Farallon Ridge	San Francisco Bay Plume	Pioneer Sea mount	Pioneer Canyon	Ascension, Cabrillo, & Año Canyons	Pt. Ano Nuevo	Monterey Canyon	Monterey Bay Inshore	Carmel Canyon	Pt. Sur Slope	Pt. Sur Shelf	Davidson Sea-mount	Estero Bay/San Luis Obispo Bay
Podicipedidae																										
Western and Clark's grebes	x	x	**X	X											X			x		X						X
Gaviidae																										
Pacific loon	X		***X									x			x			x		X			X			
Diomedidae																										
Black-footed albatross	***X	x	x		X	X	X	x		X		X	X				x	x		X		x	x			
Laysan albatross	x	o	***X		X	X	X	x	X				X													
Procellariidae																										
Northern fulmar	x	x	***X		X	X	X	x		x	x	x	X	x			x	x		x		x	x			
Sooty shearwater	***X	x	o	X	X	X	x	x		X	x	x	x	x	X		X	X		X	X	x				X
Short-tailed shearwater	o	o	***X		X	X	x	x				X														
Pink-footed shearwater	***X	x	o	X	X	X	x	x		x			x	X	x			x		X			x			
Buller's shearwater	o	***X	o		X	X	X	x	X			x	X	x		x	x	x		x					x	
Black-vented shearwater	o	**X	x		X	X								x	X	x		x		x						
Hydrobatidae																										
Leach's storm-petrel	**X	**X	o					X	X				X			x	x	x							x	
Fork-tailed storm-petrel	o	o	X		x	X	X	x	X				X			x		x							x	
Ashy storm-petrel	**X	***X	**X		x	X	X	x	X	x	X		X				x	x		X					x	
Black storm-petrel	o	**X	**X		x	X	X					X					x	x		X			x			
Anatidae																										
White-winged scoter	o	x	**X	X											X						X					X
Surf scoter	o	x	**X	X											X						X					X
Pelecanidae																										
Brown pelican	**X	**X	x	X	x					x				x	X			X			X			x		X
Phalacrocoracidae																										
Brandt's cormorant	***X	***X	***X	X	X					x		x	x	X	X			X		X				x		x
Pelagic cormorant	**X	**X	**X	X								x		X	x			x								x
Double-crested cormorant	*X	o	o						X			x		X	X						x					x
Scelopacidae																										
Red phalarope	***X	x	o		X	X	X	x	X		x		X				x	x		x			x		x	
Red-necked phalarope	***X	x	o	X	X	x	x			x	x	x		x			x	x		x			x			x
Laridae																										
Glaucous-winged gull	o	x	***X	X	X	x				x	x	x		x	X		x	x			X					X
Western gull	***X	***X	***X	X	X	X	x			x	x	X	X	X	X				X		X			x		X
California gull	o	x	***X	X	X	x						x			X				x		X			x		X
Ring-billed gull	o	x	**X	X	x										X						X			x		X
Mew gull	o	x	**X	X	x										X						X					
Heermann's gull	o	x	**X	X	x										X						X					
Bonaparte's gull	***X	x	o	x	X	X	x										X	x		X						
Sabines gull	***X	x	o				X	X	X		x		X				x	x		X						
Black-legged kittiwake	x	o	***X		X	X	X	x	X		x	x	X			x	x	x		x		x			x	
Caspian/Elegant terns	**X	x	o	X											X					X						x
Arctic tern	***X	***X	o			x	x	X	X		x		X			x	x	x		x						
Forster's tern	**X	x	o	X											X					X						
Alcidae																										
Common murre	***X	***X	***X	X	X	x	x			x		x	x	X	X				x		x			x		x
Pigeon guillemot	**X	x	o	X	X									X				x								X
Tufted puffin	*X	x	o		x	X	X	X					X	X			x									
Rhinoceros auklet	***X	***X	x		x	X	X			x		x	x	x			x	x	X	x		x	x			
Cassin's auklet	***X	***X	x		X	X	x			X		X	X	X			x					x				
Marbled murrelet	*X	*X	*X	X														x	X		X					
Xantus/Craveri's murrelets	***X	x	x			X	X	X	X				X													
All Xs	29	35	27	21	28	24	22	16	11	13	14	14	22	17	20	6	18	19	11	15	18	6	8	8	6	16
Large X's	25	14	21	20	19	19	13	5	11	3	1	4	16	9	17	0	2	1	5	7	16	0	8	2	0	10

Notes

1. A summary of temporal and spatial patterns in the occurrence of 44 marine birds off north/central California, based on visual inspection of the species' seasonal density maps by the principal investigators.

2. The spatial and temporal patterns summarized here may be affected by variation in the sampling effort of the combined data sets; that said, this table is included because it provides a summary of the relative use of the various habitat features, as viewed in the species maps.

3. In the "seasonal occurrence" columns, the number of asterisks indicate the number of sanctuaries in the study area that are used by the species during the season. A large "X" means a relatively major occurrence in the data sets, a small "x" means a minor occurrence, and a "o" means the species was mostly absent.

4. Under the heading for "large, bathymetrically-defined areas", a large "X" indicates where the species was most abundant, a small "x" means a minor occurrence, and a "o" means the species was mostly absent.

5. Under the heading for "discrete physiographic/oceanic features", large X's refer to 'hot spots'; small x's indicate areas of secondary importance for that species.

6. A blank in the table means a species was not present at the location indicated in the maps/data reviewed.

Phalaropes can also be very abundant but don't contribute much biomass and they are also most abundant over the shelf waters. Smaller-scale biomass and density hot spots are also the same, e.g. inner Monterey Bay, San Francisco Bay tidal plume, the area around the Farallon Islands, Pioneer and Ascension Canyons, and Cordell Bank. Moreover, as will be noted later (see also below) density and biomass are more spread out during warm-water than during cold-water or neutral periods.

Seemingly, highest biomass occurred during the Upwelling and Oceanic seasons, as was the case for density. Any seasonal difference was least clear in regard to density.

Diversity. To assess species diversity, the Shannon Index (Shannon and Weaver 1949) and species density data were used (see Figure 54). This index measures the degree to which the species assemblage is dominated by a single species. For example, if "Species A" dominates all the species seen within a cell, then diversity is low; and if all species are "evenly" represented, then diversity is high. Diversity was calculated using all bird species (n=76) in the data set, for each ocean season and for all ocean seasons combined.

Highest diversity indices are about the same in all three seasons. In all cases, at the smaller spatial scale (less-detailed), species diversity was greatest along the continental slope. This is expected given that the slope habitat constitutes the boundary as well as the overlap between the shelf and oceanic habitats. At a larger scale (more detailed), in all seasons there was an area of notable diversity seaward of the Farallon Islands (Farallon Escarpment) and to some degree outside of the sanctuary boundaries. Likely the diversity here resulted from a coincidence of occurrence of: 1) oceanic species; 2) shelf species; 3) Farallon breeding species that would not occur offshore were it not for the Farallones; and 4) the location of a persistent boundary there of a coastal upwelling front that extends southwestward from Point Arena. Accordingly, during La Niña, when upwelling features are well developed, this area exhibits much greater diversity than is apparent during El Niño.

Although there was a significant correlation between bird diversity and effort, the observed patterns of bird diversity are robust and were largely unchanged by methods designed to correct for effort. See an additional discussion of bird diversity in the Integration section.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

Important Marine Areas for Birds: Considering Overall Biomass, Density and Diversity of Marine Birds. All marine habitat off central California, especially that of the continental shelf and slope, is fully used by marine birds. Based on the analyses of maps for overall density, biomass density, and diversity, the following at-sea areas were identified as important (Table 17). Areas with more and bigger Xs may be more important, as they show more expression of density, biomass and diversity.

Important Breeding Colonies for Marine Birds. Although breeding colonies and roosts are on land and technically not part of the study area, a table and map of the major colonies are included in this section because they provide a context for understanding the distributions of species that breed or roost in the study area based on size and species composition (most data was from Carter et al., 1992, with updates, as available). Table 18 shows the top 40 marine bird breeding colonies in the study area; see Figure 55 for a map of these locations; see the CD-ROM X for a full listing of breeding sites.

Marine birds in this area breed mainly during the Upwelling Season, anticipating that food availability will be greatest from July-October, toward the end of this season and into the Oceanic Season. During this period ample supplies of prey will be needed to feed growing chicks and recently fledged young. Egg laying occurs in March-May, depending on species, and different species require different amounts of time to complete the breeding task (petrels longest, gulls shortest).

The greatest concentration of colonies occurs in the Gulf of the Farallones, in the broad shelf area from Point Reyes south to Año Nuevo and out to the Farallon Islands. The breeding avifauna is dominated by alcids, with six species. Fifteen species of marine birds breed at sites within or immediately adjacent to the National Marine Sanctuaries in the study area; several others breed inland or in San Francisco Bay and to a lesser degree use marine sanctuary waters.

Importance of Ocean Seasons to Marine Birds. As seen in the maps for individual species, temporal differences in species occurrence patterns are strong for many species in the study area (see Tables 15 and 16). Below is a brief summary of marine bird activity in the three ocean seasons.

Upwelling Season (~Spring/Summer). With the onset of upwelling, when cold, nutrient-rich water is brought to the surface by persistent northwest wind and the Coriolis effect, most of the seasonal winter residents depart and several other species migrate through the region (e.g. Sabine’s Gull, Arctic Tern). Arriving are several species that nest in the Southern Hemisphere, thus spending their ‘wintering’ period in the region. The Sooty

Shearwater is one of these and becomes the most abundant species in the study area.

Owing to the addition of Sooty Shearwaters to the avifauna and the continued abundance of Common Murres, overall density and biomass of marine birds is highest during the Upwelling and Oceanic Seasons and is widely spread from the coast to beyond the shelfbreak. Diversity over the shelf, where the shearwaters and murres mostly reside, is relatively low.

Oceanic Season (~Autumn). In this season, when upwelling winds have noticeably relaxed, allowing offshore, warmer oceanic water to flow shoreward, the avifauna begins to diversify. However, as more sooty shearwaters and other southern hemisphere seasonal residents depart the avifauna

Biomass remains high but shifts closer to shore than during the Upwelling Period, in large part due to an inshore shift of murres and shearwaters.

Davidson Current Season (~Winter). During this season, when ocean temperatures are relatively warm and there is no upwelling (but frequent downwelling owing to southerly storms) the area is inundated by such species as black-legged kittiwake, northern fulmar and several larger gulls. All these species nest outside of the region. Also present are nesting species that reside year-round in the region, such as Brandt’s cormorant, western gull, common murre, rhinoceros auklet and Cassin’s auklet. In fact, many of the latter species begin to occupy nesting colonies during this season, well before the nesting period.

Table 17. Important at-sea areas and ocean seasons for marine birds off north/central California, based on maps of biomass, density and diversity.

Area	Biomass/Density			Diversity		
	Davidson Current Season	Upwelling Season	Oceanic Season	Davidson Current Season	Upwelling Season	Oceanic Season
Cordell Bank	x	X				
Farallon Escarpment (slope)	X	x	x	X	X	X
Farallon Ridge (includes Farallon Island area)	X	X	x			
San Francisco Bay Tidal Plume		x	X	X		
Pioneer Canyon				X	x	x
Año Nuevo Shelf	X		X			
Ascension, Año and Cabrillo Canyons	X	x	x	X	x	
Monterey Bay Inshore	X	x	X	X		
Monterey Bay Canyon	X		x			
Carmel Canyon				X		
Point Sur Shelf			x			
Point Sur Slope				X	x	
Estero Bay & San Luis Obispo Bay	X		x			

Note: Large, bold Xs refer to most important areas, and smaller xs refer to other important areas.

becomes more sparse. At this time, resident breeding species are also dispersing more widely as they finish breeding duties.

Additionally, several species (e.g., phalaropes, jaegers, Arctic terns, Sabine’s gulls) are migrating through the region, the local nesting species are all present, and several species that nest elsewhere are abundant as well (e.g. several shearwaters, brown pelican, and Heermann’s gull).

During this season, the species diversity of shelf waters increases. In fact, areas of high diversity are more widespread in this season than in the others.

Analysis of Variation in Species Abundance Patterns. Many factors influence the distribution and abundance of marine birds; in this study, the effects of nine independent variables on species density were investigated for 26 species. The data used for the regression analyses were a subset of the mapped data, and included data from the Davidson Current Period from 1985 through the same for 2002; also, cells with area surveyed less than 0.25km² were excluded.

Among the nine variables investigated, the three most important variables that explained variation in species density were “Distance to Land” (16 of 25 species), “Ocean Season” (13 species), and “Ocean Depth” (11 species, see Table 19).

The next three variables of importance were “ENSO” (eight species), “Year” (seven species), and “Distance to Colony”. In some respects, for species having many small colonies (e.g. pelagic cormorant), Distance to Land and Distance to Colony may have co-varied. The variable “Year” indicated whether there was an increasing or decreasing trend in the species’ abundance. An effect of ENSO would indicate an especially complex relationship, possibly meaning either an effect of prey availability or ocean climate.

Please note that while the three most important variables of those evaluated are indicated in Table 19, for most species there are likely other variables of greater importance (e.g., prey availability, depth of thermocline). On average, only about 20% of the variance was explained with the top three variables presented. Additional data and time would be required to evaluate other variables that might be of greater importance in explaining the variation in a species’ distributions.

Species Use of the Water Column. Several marine bird species are capable of exploiting the entire water column of the shelf, e.g. Pacific loon, western/Clark’s grebes, and common murre, but for unknown reasons (possibly prey selection, perhaps interference competition from murres and shearwaters) the grebes mainly frequent the inner most portion of the shelf. The very abundant common murre is found everywhere on the shelf especially during the breeding/Upwelling season. Other diving species, such as scoters or marbled murrelet, frequent only shallow waters of the inner shelf, while other species, such as tufted puffin, rhinoceros auklet and Cassin’s auklet frequent waters much deeper (continental slope) than their diving capabilities allow. Species such as the very abundant sooty shearwater (a shallow diver to 20 meters) are found everywhere from outer slope to inner shelf.

These differences in patterns of habitat use are likely related to factors such as the occurrence patterns of different prey (species/sizes), interspecific competition, or temporal occurrence of certain prey (species/sizes). The latter would account for why some year-round resident species feed over waters of different depths during one season compared to another. Species such as the sooty shearwater, which use a wide range of ocean depths and habitats, are likely to be more generalized in prey selection, possibly due to their fast, efficient flight allowing them to forage over much larger areas than many other marine birds, particularly the alcids and cormorants.

Response to “Short-Term” Changes in Ocean Climate. The study area is subjected frequently to shifts in marine climate of different scales and periodicity and this makes management a challenge, because populations are affected by natural environmental factors that cannot be addressed proactively

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

Table 18. Major marine bird colonies along the central California coast

Colony/Composite Name	CA Colony Number	USFWS Colony Number	Latitude	Longitude	Leach's Storm-Petrel	Ashy Storm-Petrel	Brandt's Cor-morant	Double-crested Cormorant	Pelagic Cor-morant	Western Gull	Caspian Tern	Common Murre	Pigeon Guillemot	Marbled Murrelet	Cassin's Auklet	Rhino-ceros Auklet	Tufted Puffin	Other Species (see notes)	Site Total (No. of Breeding Birds)
Fish Rocks	ME-384-10	404-003	38°47'59" N	123°35'31" W	100		211		123	170			119		P	4	15	6	748
Gualala Point Island	SO-384-01	404-004	38°45'3" N	123°31'42" W			521		4	26			29					1	581
Russian Gulch	SO-382-08	404-033	38°28'0" N	123°9'35" W					227	42			20					7	296
Russian River Rocks	SO-382-09	404-005	38°27'14" N	123°8'34" W			51	422	125	44			5					2	649
Arched Rock	SO-382-11	404-006	38°25'53" N	123°7'31" W			717		9	34			2						762
Bodega Rock	SO-380-02	404-008	38°17'48" N	123°2'49" W			1,228			24			30			2			1,284
Bird Rock	MA-380-04	404-010	38°13'49" N	122°59'35" W		15	55		37	168			115			3	H	6	399
Point Resistance	MA-374-03	429-024	37°59'54" N	122°49'40" W		P	46	H	H	8		3,518	50						3,622
Point Reyes	MA-374-01	429-001	37°59'30" N	122°58'59" W		15	1,522		266	178		15,155	616				4	6	17,762
Millers Point Rocks	MA-374-04	429-002	37°58'52" N	122°48'34" W			114		59	30		358	55					1	617
Double Point Rocks	MA-374-05	429-003	37°56'50" N	122°47'8" W		30	180		9	8		4,464	22						4,713
San Francisco Bay & Alcatraz Island	Composite	Composite	37°49'33" N	122°25'19" W			9	2,789	4	4,174	2,818		10					8498	18,302
North Farallon Islands	SF-FAI-01	429-051	37°46'4" N	123°5'56" W			161		62	32		27,308	42						27,605
South Farallon Island	SF-FAI-02	429-052	37°42'0" N	123°0'0" W	1,400	1,990	9,466	486	442	15,095		103,588	499		18,807	516	128	30	152,447
Devil's Slide Rock	SF-372-03	429-014	37°34'28" N	122°31'39" W			7		46	16		246	30						345
Big Basin State Park and vicinity	None	None	37°8'48" N	122°17'58" W										600					600
Vicinity of Año Nuevo Island and Point	Composite	Composite	37°6'30" N	122°20'8" W			4		117	1,382			219		24	224		27	1,997
Greyhound Rock to El Jarro Point	SC-370-01	429-049	37°3'31" N	122°15'0" W					66	2			321					9	398
El Jarro Point to Davenport	SC-370-02	429-050	37°1'5" N	122°12'23" W			308		22				313			1			644
Davenport to Sand Hill Bluff	SC-364-01	454-038	36°59'44" N	122°10'32" W					13				495					1	509
Cannery Row	MO-362-02	454-044	36°36'46" N	121°53'47" W					198	86			88						372
Bird Rock	MO-362-03	454-006	36°35'30" N	121°57'59" W			2,651			16								2	2,669
Guillemot Island Area	MO-362-06	454-023	36°31'45" N	121°56'47" W			554		20	30			18					10	632
Bird Island	MO-362-09	454-009	36°30'24" N	121°56'32" W			6,151		4	90			5					2	6,252
Castle Rocks and Mainland	MO-362-19	454-010	36°22'35" N	121°54'25" W		P	750		46	12		1,050	19						1,877
Hurricane Point Rocks	MO-362-20	454-011	36°21'40" N	121°54'25" W		P	29		H	14		613	20				H		676
Anderson Canyon Rocks	MO-360-13	454-016	36°9'7" N	121°39'53" W			321	5	26	2			32						386
Burns Creek Rocks	MO-360-14	454-017	36°8'29" N	121°39'28" W			323			2			12						337
Plaskett Rock	MO-354-07	477-002	35°55'13" N	121°28'41" W			849		H	5			H					1	855
Cape San Martin	MO-354-08	477-003	35°53'16" N	121°27'54" W			750	2	18	349			H						1,119
Redwood Gulch Rock	MO-354-12	477-005	35°50'19" N	121°24'3" W			372			2			H						374
La Cruz Rock	SL-354-04	477-006	35°42'22" N	121°18'45" W			678			18									696
Piedras Blancas Island	SL-352-01	477-007	35°39'51" N	121°17'17" W			2,627			34			29			3	H	1	2,694
Morro Rock and Pillar Rock	SL-352-07	477-026	35°22'13" N	120°52'8" W			117	24	53	114			24						332
Fairbank Point	SL-352-08	477-044	35°21'5" N	120°50'37" W				331											331
Unnamed Rocks	SL-350-03	477-010	35°14'40" N	120°53'38" W					174	49			242					6	471
Lion Rock	SL-350-05	477-011	35°13'3" N	120°52'16" W			277		H	24			18					1	320
Pup Rock and Adjacent Mainland	SL-350-04	477-028	35°13'17" N	120°52'13" W			1,309			44								2	1,355
Pecho Rock	SL-350-09	477-032	35°10'45" N	120°48'59" W			321			14									335

Table Notes

- This table contains numbers of breeding birds at specific colonies or composite sites, for the species indicated. The table shows the best available data for approximately 40 of the largest colonies and colony composites for selected marine birds that occur in the study area. All colonies shown have 296 or more breeding birds, and sites are listed from north to south.
- The primary source for these data is Carter et al. 1992 (unpublished data); most estimates from this source were made from 1989-1991. Older data older data are indicated by italics (e.g., data for Leach's storm-petrel), and more recent or updated data (from various sources, identified below) are indicated in bold type.
- Key to symbols in table: H=historically nesting species; P = present and probably breeding. A blank in the table for a species/colony cell means the species was not present in the available data.
- The column titled "Other Species" contains available estimates for all other breeding bird species. For most sites, this includes Black Oystercatcher. For the San Francisco Bay/Alcatraz composite site, the "Others" estimate includes California Gull, Forster's Tern, and Least Tern, which breed at sites in the Bay.
- For Ashy Storm-petrel, the updates at Bird Rock, Point Reyes and Double Point are from 2001 (Whitworth et al. 2002). The update at South Farallon Island is from 1992 (Sydeman et al. 1998).
- The estimate of 600 breeding Marbled Murrelets at Big Basin State Park and Vicinity was provided by Laird Henkel, pers. comm.
- For Cassin's Auklet and Rhinoceros Auklet, the updates in the vicinity of Año Nuevo are from 2002 and do not include the small breeding area within the Brandt's Cormorant colony. Sources: Thayer and Sydeman 2002a,b.
- The estimates of breeding birds for Leach's Storm-petrels are in italics and from Ainley and Lewis (1974); these older estimates are likely much higher than the current colonies' status. The number of breeding birds at Fish Rock has likely significantly decreased; in August 1989, no Leach's Storm-petrels were captured at Fish Rocks, but this may be due to low sample effort (Harry Carter, pers. comm). And based on annual mark-recapture efforts since 1992, the number of breeding birds at S. Farallon Island has also likely significantly decreased (Bill Sydeman, pers. comm.).
- Updates from 2002 (in bold) are included for the following eight species at South Farallon Island: Cassin's Auklet, Common Murre, Tufted Puffin, Pigeon Guillemot, Double-crested Cormorant; Pelagic and Brandt's cormorants, and Western Gull. Source: Warzybok et al. 2002.
- The 2002 update for 246 breeding Common Murres at Devil's Slide Rock was provided by Gerry McChesney, U.S. Fish and Wildlife Service.
- Fork-tail Storm-petrels have been noted as present and probably breeding at South Farallon Island, but no estimate is available.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

Table 19. Three most important variables (of nine investigated) having independent effects in explaining the variance in density of 25 selected marine bird species.

Species	Number of Birds Recorded During Surveys	Percent Variance Explained by Top Three Variables	Three Most Important Variables of Those Investigated, in Order of Importance
Pacific loon	3,802	10.6	Ocean season, distance to land (-), latitude (-)
Western grebe	7,080	15.5	Ocean season, distance to land (-), ocean depth (-)
Black-footed albatross	3,149	22.2	ocean depth (+), distance to land (-), year (-)
Laysan albatross	96	6.9	Ocean season, ocean depth (+), distance to land (+)
Northern fulmar	5,882	21.3	Ocean season, ENSO period, year (+)
Sooty shearwater	296,065	43.4	Ocean season, year (-), ENSO period
Pink-footed shearwater	4,145	13.1	Ocean depth (-), distance to land (-), ENSO period
Leach's storm-petrel	1,414	28.4	Ocean season, distance to 2000m isobath (+), ENSO period
Ashy storm-petrel	4,201	17.3	ENSO period, season, year (+)
Fork-tailed storm-petrel	393	9.2	ENSO period, season, ocean depth (+)
Brown pelican	2,333	15.2	Distance to land (-), latitude (-), Ocean season
Brandt's cormorant	9,482	28.7	Distance from colony (-), dist. to 200 m isobath, dist. to land (-)
Pelagic cormorant	396	6.1	Distance to land (-), ocean depth (-), dist. to 200 m isobath (-)
Double-crested cormorant	300	9.7	Dist. from colony (-), dist. To 200m isobath (-), dist. to land (-)
Red & Red-necked phalaropes	49,195	9.6	ENSO period, distance to land (-), ocean depth (-)
Western gull	29,545	44.2	Distance from colony (-), distance to land (-), ENSO period
Glaucous-winged gull	767	17.1	Ocean season, ocean depth (-), latitude (+)
Heermann's gull	1,121	6.5	Distance to land (-), ENSO period, latitude (-)
California gull	13,721	24	Ocean season, year (+), latitude (+)
Black-legged kittiwake	4,565	28.9	Ocean season, ENSO period, year (+)
Common murre	131,675	52.3	Distance to colony (-), ocean depth (-), distance to land (-)
Rhinoceros auklet	14,679	19.8	Distance to land (-), season, ocean depth (+)
Tufted puffin	235	10.1	Distance from colony (-), year (-), distance to 200 m iso (+)
Cassin's auklet	63,465	25.8	Distance to land (-), year (-), ocean depth (-)
Marbled murrelet	273	4.7	Distance to land (-), latitude (+), ENSO period

- Notes
1. For “continuous” variables, a positive (+) included with a variable indicates that density increased with an increase in the magnitude of that variable; (-) denotes the opposite.
 2. The nine independent variables used in the regression analysis were: distance to nearest land; ocean season; ocean depth; ENSO period; year; latitude; distance to colony; distance to 200m isobath; and distance to 2,000m isobath.
 3. Species that breed in the study area are shown in bold.

by management. The individual species text (accompanying each map) details where selected species become more or less abundant in north/central California during periods of warmer or colder than average ocean temperatures. Actually, the shift in temperature is a proxy for many other changes, all of which ultimately affect the food web.

To illustrate the short-term ocean climate effects using species maps, a comparison was done using selected species density maps for a specific El Niño and La Niña period. For the El Niño period, the most recent, and very intense El Niño event, Oceanic Season 1997 through Upwelling Season 1998, was used; for the La Niña event, the period covering the Oceanic Season 1998 through Oceanic Season 1999 was used. These

two periods were chosen because climate differences were extreme, i.e. among the strongest ENSO events of the past 100 years, and they occurred adjacent to one another. Therefore, a comparison of population response was not confounded by long-term trajectories in base population size. Tables 20 and 21, as well as Figure 58, provide some examples of these changes due to interannual climate events (see Table 14).

Warm-water Periods (e.g., El Niño events). During warm-water events (including El Niño), many marine bird species tended to occur closer to shore than during other years (Ainley and Boekelheide 1990, Oedekoven et al. 2001). During warm-water periods, five of the predominant species became more abundant in central California waters in general, and inside

the marine sanctuaries; these species include pink-footed shearwater, Leach's storm-petrel, and western, glaucous-winged and Heermann's gulls; see Table 20 below. Also increasing in the study area during warm-water periods were less abundant species including black and least storm-petrels and black-vented shearwater.

Cold-water Periods (e.g., La Niña events). During coldwater periods, areas of relatively high avifaunal biomass and density expanded to cover broader portions of the study area; 11 of the predominant species became more abundant. Species whose abundance showed the greatest increases were the western grebe, northern fulmar, ashy storm-petrel, red and red-necked phalaropes (grouped), and black-legged kittiwake (Table 20). Others, whose abundance were also significantly greater during La Niña periods were Pacific loon, Laysan albatross, California gull, rhinoceros auklet, and marbled murrelet.

Neutral Periods (i.e., neither unusually warm nor cold water). Four species, black-footed albatross, sooty shearwater, tufted puffin and Cassin's auklet were significantly more abundant during the neutral period than during the warm or cold periods.

Other Responses to Short-Term Climatic Change. In regression analyses, the densities of the brown pelican and fork-tailed storm-petrel were not significantly different during warm-water and cold-water periods. Basically, this was because such periods varied greatly in intensity, thus reducing effects especially if other factors (not studied) were more important. However, the densities of

both were greater during these periods than during the Neutral period. On the other hand, the brown pelican responded strongly to the disparity of conditions between the very strong 1997-98 El Niño and the very strong 1999-00 La Niña (Figure 59). The black-vented shearwater, for which there were insufficient data for long-term trend analysis, responded much more dramatically, with large numbers invading central California waters during the 1997-98 El Niño. Finally, there were no significant differences

Table 20. Effects of ocean season and ENSO events on the abundance of 26 marine bird species off central California between 1985 and 2002, as determined through multiple regression analyses.

Species	Ocean Season(s) of Highest Abundance*	ENSO Event of Highest Abundance*
Pacific Loon	DC	LA
Western Grebe	DC	LA
Black-footed Albatross	UP	NE
Laysan Albatross	DC	LA
Northern Fulmar	DC	LA
Sooty Shearwater	UP	NE
Pink-footed Shearwater	OC	EL
Leach's Storm-Petrel	DC/UP	EL
Ashy Storm-Petrel	OC	LA
Fork-tailed Storm-Petrel	DC	LA/EL
Brown Pelican	OC	LA/EL
Brandt's Cormorant	UP	ns
Pelagic Cormorant	UP	ns
Double-crested Cormorant	UP	ns
Red & Red-necked Phalaropes	OC	LA
Western Gull	UP	EL
Glaucous-winged Gull	DC	EL
Heermann's Gull	ns	EL
California Gull	DC	LA
Black-legged Kittiwake	DC	LA
Common Murre	UP	ns
Rhinoceros Auklet	DC	LA
Tufted Puffin	UP/DC	NE
Cassin's Auklet	UP	NE
Marbled Murrelet	DC/UP	LA

* Notes. Ocean seasons are: Davidson Current (DC), Upwelling (UP), and Oceanic (OC); ENSO periods are El Niño (EL), La Niña (LA), and neutral (NE). For species having significant differences in abundance during respective seasons/periods (Sidak tests, P < 0.01), the season/period in which they were most abundant is given. If densities did not differ between the two seasons/periods in which they were most abundant, then the two are listed (eg. DC/UP, where densities were slightly higher in DC season than the UP season). Species for which there was no significant effect of season or period are denoted with “ns”.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

Table 21. A summary of changes in marine bird occurrence patterns, as a response to warm and cold ocean anomalies, as determined by visual comparison of species’ maps during the 1997-1998 El Niño event and the 1999-2000 La Niña event.

Species	Effect on Distribution		
	No Change	El Niño	La Niña
Western grebe	X		
Pacific loon	X		
Black-footed albatross	X		
Laysan albatross	X		
Northern fulmar			More spread
Sooty shearwater		To Monterey Bay	
Pink-footed shearwater	X		
Buller’s shearwater	X		
Black-vented shearwater		To Gulf of Farallones	
Leach’s storm-petrel	X		
Ashy storm-petrel		More spread	
Fork-tailed storm-petrel	X		
Black storm-petrel		To Gulf of Farallones	
Brown pelican		More spread	
Brandt’s cormorant		More spread	
Pelagic cormorant		More spread	
Red phalarope	X		
Red-necked phalarope	X		
Glaucous-winged gull		More confined	
Western gull	X		
California gull		More confined	
Heermann’s gull			
Bonaparte’s gull		To Monterey Bay	
Sabine’s gull	X		
Black-legged kittiwake		Confined to slope	More spread
Caspian tern	X		
Elegant tern	X		
Arctic tern	X		
Common murre		More spread	
Pigeon guillemot		More spread	
Tufted puffin		More spread	
Rhinoceros auklet	X		
Cassin’s auklet		More spread	
Marbled murrelet		More offshore	
Xantus/Craveri murrelets	X		

in the abundance of common murre and the three cormorant species among the three climate-related periods.

Breeding species (e.g. common murre, Cassin’s auklet) whose populations are not increased by an influx of visitors from colonies outside the study area during warm-water periods, and the cormorant species, are more dispersed during the

breeding season during warm-water periods (Table 21). This spreading is often affected most strongly by Farallon breeding species, which usually concentrate near the Gulf of the Farallones (outer shelf), and which move more to coastal waters.

Population Trends. Owing mainly to longer-term, decadal shifts in marine climate (Hare and Mantua, 2000, Mantua and Hare 2002), a number of species exhibited gradual changes in population size within the study area, from 1985 to 2002. These patterns were revealed using regression analyses, especially in cases where Year was an important explanatory variable to species occurrence (Table 19).

Ashy storm-petrel and California gull exhibited a gradual increase in population (from 1985-2002); Tufted puffin showed a gradual decrease. The Black-legged kittiwake increased gradually, too, but was especially abundant after 1998 (Figure 60).

For other species the pattern was more complex. Black-footed albatross, sooty shearwater, fork-tailed storm-petrel and Cassin’s auklet showed a gradual decrease from 1985 until about 1999, when they began to increase.

The year 1999 is when the system likely shifted from a ‘warm’ to a ‘cold’ ocean regime (Bogard, 2000; Schwing and Moore, 2000). The northern fulmar exhibited a variable but ‘steady’ population size during the 1980s and early 1990s but then began to increase with arrival of the ‘cold’ regime. The population of the common murre remained stable through most of the study period following a dramatic decline in 1982 (Ainley and Divoky 2001, Manuwal and Carter 2001), but recently it has begun to increase (H. Carter, pers. comm.). These responses to decadal regime shifts present challenges to the researchers and managers even greater than those offered by short-term climate shifts (e.g., ENSO events). It takes several years of monitoring to detect long-term shifts in population size.

Relevance of Marine Sanctuary Boundaries to Marine Birds. Based on the available data, the boundaries of the

national marine sanctuaries off north/central California generally encompass the areas of high concentrations and diversity for marine birds, except for the western edge of the Gulf of Farallones area and the "sanctuary exclusion area" off San Francisco and Pacifica.

Owing perhaps to a response to competition for food by the large numbers of marine birds nesting on the Farallon Islands and Point Reyes Headlands, during the breeding (Upwelling) season high concentrations of several breeding species extend seaward of the western boundary of the Gulf of the Farallones National Marine Sanctuary, over the Farallon Escarpment and beyond. This is especially true of Ashy Storm-petrel, Western Gull, Common Murre, and Rhinoceros Auklet. For the gull and murre these deeper waters are not their preferred foraging habitat, but they choose to forage there during breeding because more suitable continental shelf habitat to the north and south is too far out of range.

To a lesser degree, a smaller high density area existed seaward of Año Nuevo Island, where there is a smaller, but important colony. These three colonies (Farallon Islands, Point Reyes Headlands and Año Nuevo Island), and the waters between them which comprise the Gulf of the Farallones, possess populations that interact regularly in the shallow waters that lie between them; many individuals marked at one have been seen at the other two sites. Therefore, in terms of marine birds the waters of the Gulf of the Farallones, as defined above, constitute a natural management unit.

In addition, it was apparent from visual inspection of the maps, that the "sanctuary exclusion area" (i.e., the ocean area off San Francisco and Pacifica that is excluded from the Monterey Bay National Marine Sanctuary) represents a very important area for marine birds, especially those that breed at localities within the Gulf of the Farallones National Marine Sanctuary (e.g. Point Reyes, Farallon Islands) (David Ainley, pers. comm.). This area is influenced strongly by the San Francisco Bay tidal plume, which provides habitat for many forage fish. This "sanctuary exclusion area" is also one of the main foraging areas of the Devil’s Slide murre colony, which is in the process of being restored (David Ainley, pers. comm.).

With regard to the offshore bounds of the sanctuaries, among the species of marine birds mapped, only 11 had significant concentrations seaward of sanctuary boundaries (see Table 16). In terms of management, it is important to consider Ashy storm-petrel and its habitat, because it is listed as a "State Species of Concern". The Xantus’ murrelet, a recently listed species, also deserves consideration, although the proportion of this species’ population that visits the central California National Marine Sanctuaries is relatively low.

MAJOR SECTION CONTRIBUTORS

David Ainley, H.T. Harvey and Associates
R. Glenn Ford, R.G. Ford Consulting Co.
Janet Casey R.G. Ford Consulting Co.
Larry Spear, H.T. Harvey and Associates
Carol Keiper, Oikonos
Lisa Ballance, Southwest Fisheries Science Center, NOAA
Tracy Gill, NCCOS, NOAA
Wendy Williams, R.G. Ford Consulting Co.
Ken Buja, NCCOS, NOAA

REVIEWERS

Two reviews were done for the marine bird analyses. The first was a workshop to review draft maps in October 2002, and the second review focused on the overall draft bird report (which contains the maps) and was conducted via email November and December, 2002. Most of the review comments were addressed or incorporated for this product, which is a summary of a full bird report to be released later this year.

Workshop Participants/Reviewers:

David Ainley, H.T. Harvey and Associates
Sarah Allen, Point Reyes National Seashore, National Park Service
Lisa Ballance, Southwest Fisheries Science Center, NOAA
Janet Casey, R.G. Ford Consulting Co.
Glenn Ford, R.G. Ford Consulting Co.
Carol Keiper, Oikonos
Nora Rojek, formerly of California Department of Fish and Game
Jan Roletto, Gulf of the Farallones National Marine Sanctuary Program, NOAA
Ed Ueber, NOAA, Gulf of the Farallones National Marine Sanctuary Program
And several other members of the NOAA project team and sanctuary programs.

Reviewers of the Draft Bird Report:

Sarah Allen, Point Reyes National Seashore, National Park Service
Scott Benson, Southwest Fisheries Science Center, NOAA
Karin Forney, Southwest Fisheries Science Center, NOAA
Doug Forsell, Chesapeake Bay Program, U.S. Fish and Wildlife Service
Laird Henkle, H.T. Harvey and Associates
David Hyrenbach, Duke University Marine Lab
Hannah Nevins, Moss Landing Marine Laboratories
Jan Roletto, Gulf of the Farallones National Marine Sanctuary Program, NOAA
Franklin Schwing, Southwest Fisheries Science Center, NOAA
And several other members of the NOAA project team and sanctuary programs.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

PERSONAL COMMUNICATIONS

Laurence Breaker, Moss Landing Marine Laboratory
Harry R. Carter, U.S. Geological Survey, Dixon CA
Laird Henkel, H.T. Harvey and Associates, San Jose CA
Michelle Hester, Oikonos, Bolinas, CA
Gerry McChesney, U.S. Fish and Wildlife Service

REFERENCES

Ainley, D.G. 1976. The occurrence of seabirds in the coastal region of California. West. Birds, Vol 7, pp. 33-68.

Ainley, D.G. Unpublished data. Shipboard surveys for seabirds at sea off northern and central California, 1985-2001. 105 Headlands Court, Sausalito, CA, 94965.

Ainley, D.G., S.G. Allen and L.B. Spear. 1995a. Offshore occurrence patterns of Marbled Murrelets in central California. Marbled Murrelet Conservation Assessment. Ecology and Conservation of the Marbled Murrelet (C. J. Ralph et al., eds.), Gen. Tech. Rept. PSW-GTR-152, U. S. Dept. Agriculture, Forest Service, Pacific Southwest Res. Station, Albany, CA. Pp. 361-370.

Ainley, D.G. and R.J. Boekelheide (eds.). 1990. Seabirds of the Farallon Islands: Ecology, Structure and Dynamics of an Upwelling System Community. Stanford Univ. Press, Palo Alto, CA. 425 pp.

Ainley, D.G. and D.F. DeSante. 1980. The Avifauna of the Farallon Islands, California. Studies Avian Biol., Vol. 4, pp. 1-104.

Ainley, D.G. and G.J. Divoky. 2001. Seabirds: Effects of climate change. Encyclopedia of Ocean Sciences (J. Steele, S. Thorpe and K. Tarekian, eds.). Academic Press, London. pp. 2669-2677.

D.G. Ainley, D.N. Nettleship, H.C. Carter & A. Storey. 2002. Common Murre (*Uria aalge*). In "The Birds of North America" (A. Poole & F. Gill, Eds.). The American Ornithologists' Union, Washington, D.C. 54 pp.

Ainley, D.G. and G. A. Sanger. 1979. Trophic relationships of seabirds in the northeastern Pacific Ocean and Bering Sea. , Conservation of Seabirds in Western North America, (J.C. Bartonek and D. N. Nettleship Eds.), U.S. Fish Wildl. Serv., Wildl. Res. Rept. 11, pp. 95-122.

Ainley, D.G., L.B. Spear and S.G. Allen. 1996a. Seasonal and spatial variation in the diet of Cassin's Auklet reveals occurrence patterns of coastal euphausiids off California. Mar. Ecol. Progr. Ser., Vol. 137, pp. 1-10.

Ainley, D.G., L.B. Spear and S.G. Allen. 1996b. Temporal and spatial variation in the diet of the Common Murre in California. Condor, Vol. 98, pp. 691-705.

Ainley, D.G., W.J. Sydeman, S.A. Hatch and U.W. Wilson. 1994. Seabird population trends along the west coast of North America: causes and the extent of regional concordance. Studies Avian Biol., Vol. 15, pp. 119-133.

Ainley, D.G., W.J. Sydeman and J. Norton. 1995b. Upper-trophic level predators indicate interannual negative and positive anomalies in the California Current food web. Mar. Ecol. Progr. Ser., Vol. 118, pp. 69-79.

Ainley, D.G., R.R. Veit, S.G. Allen, L.B. Spear and P. Pyle. 1995c. Variations in seabird numbers in the California Current, 1986-1994. Calif. Coop. Ocean. Fish. Investig., Repts. Vol. 36, pp. 72-77.

Allen, S.G. 1994. The distribution and abundance of marine birds and mammals in the Gulf of the Farallones and adjacent waters, 1985-1992. PhD thesis Univ. California, Berkeley. 222 pp.

Ballance, L.T. 2001. Unpublished data. Ecology Program, Southwest Fisheries Science Center, 8604 La Jolla Shores Drive, La Jolla, CA 92037. Lisa.Ballance@noaa.gov; <http://swfsc.nmfs.noaa.gov/PRD/ecology/ecology.html>
Metadata available from Philbrick et al. 2003.

Baltz, D.M., and G.V. Morejohn. 1977. Food habits and niche overlap of seabirds wintering on Monterey Bay. Auk, Vol. 94, pp. 526-543.

Bograd, S.J., P.M. Digiacomo, R.Durazo, T.L.Hayward, K.D.Hyrenbach, J.J.Lynn, A.W.Mantyla, F.B. Schwing, W.J.Sydeman, T.Baumgartner, JB.Lavaniegos, CS.Moore. 2000. The State of the California Current, 1999-2000: Forward to a new regime? Calif. Coop. Ocean. Fish. Investig., Repts., Vol. 41, pp. 26-52.

Bolin, R. L. and D. P. Abbott. 1963. Studies on the marine climate and phytoplankton of the central coastal area of California, 1954-60. Calif. Coop. Ocean. Fish. Investig., Repts., Vol. 9: pp. 23-45.

Briggs, K.T., and E.W. Chu. 1987. Trophic relationships and food requirements of California seabirds: updating models of trophic impact. Seabirds: Feeding Ecology and Role in Marine Ecosystems (J.P. Croxall, Ed.). Cambridge Univ. Press, Cambridge, UK. Pp. 279-304.

Briggs, K.T., W.B. Tyler, D.B. Lewis, and K.F. Dettman. 1983. Seabirds of Central and Northern California, 1980-1983: Status, Abundance, and Distribution. Part of Investigator's Final Report, Marine Mammal and Seabird Study, Central and Northern California, Contract No. 14-12-0001-29090. Prepared by Center for Marine Sciences, University of California, Santa Cruz, for the Pacific OCS Region, Minerals Management Service. OCS Study MMS 84-0043. 246 pp.

Briggs, K.T., K.F. Dettman, D.B. Lewis, and W.B. Tyler. 1984. Phalarope feeding in relation to autumn upwelling off California. Conservation of Seabirds in Western North America (J.C. Bartonek and D.N. Nettleship, Eds.). U.S. Fish Wildl. Serv., Wildl. Res. Rept., Vol. 11, pp. 51-62.

Briggs, K.T., W.B. Tyler, D.B. Lewis, D.R. Carlson. 1987a. Bird communities at sea off California: 1975 to 1983. Studies Avian Biol., Vol. 11, pp. 1-74.

Briggs, K. T., D. G. Ainley, D. R. Carlson, D. B. Lewis, W. B. Tyler, L. B. Spear, and L. A. Ferris. 1987b. Final Report: California Seabird Ecology Study. Prepared by the Institute of Marine Sciences, University of California, Santa Cruz, for the Pacific OCS Region, Minerals Manage. Serv., Contract No. 14-12-001-30183. vii and 153 pp

California Department of Fish and Game, Office of Spill Prevention and Response (CDF&G-OSPR) aerial surveys off California, 1994-2001. Sacramento, CA.

Carter, H. R., G.J.McChesney, D.L. Jaques, C.S. Strong, M.W. Parker, J.E. Takekawa, D.L. Jory, and D.L. -Whitworth. 1992. Breeding Populations of Seabirds in California, 1989-1991. U.S.Fish Wildl. Serv. Unpubl. Report, Pacific OCS Region, Minerals Manage. Serv., Los Angeles CA.

Carter, H.R., G.J. McChesney, D.L. Jaques, D.L. Jory, C.S. Strong, M.W. Parker, J.E. Takekawa, D.L. Jory, and D.L. Whitworth. 1992. Breeding Populations of Seabirds in California, 1989-1991. Draft Final Report prepared by U.S.Fish and Wildlife Service, Northern Prairie Wildlife Research Center and San Francisco Bay National Wildlife Refuge Complex, for the Pacific OCS Region, Minerals Management Service, under Inter-agency Agreement No. 14-12-001-30456 with the USFWS. 155 pp.

Chu, E.W. 1984. Sooty Shearwaters off California: diet and energy gain. Marine Birds: Their Feeding Ecology and Commercial Fisheries Relationships (D.N. Nettleship, G. A. Sanger and P.F. Springer, Eds.). Canad. Wildl. Serv., Ottawa. pp. 64-71.

Cogswell, H.L.1977. Water birds of California. California natural History Guide 40, Univ. California Press, Berkeley and Los Angeles, 399 pp.

Dunning, J.B. 1993. Body Weights of 686 Species of North American Birds. Internatl. Wildl. Rehab. Council, Univ. Georgia, Athens, GA. 59 pp.

Ford, R.G. and J. L. Casey. 2003. CDAS Density Maps for Marine Birds off North/Central California, developed for NOAA's National Centers for Coastal Ocean Science. Portland, Oregon. 49 pp.

Glantz, M.R., and J.D. Thompson. 1981. Resource Management and Environmental Uncertainty. Wiley, New York. 63 pp.

Hare, S.R., and N.J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Progr. Oceanogr., Vol. 47, pp. 103-145.

Kleinbaum D.G., L.L. Kupper, and K.E. Muller. 1988. Applied regression analysis and other multivariable methods. PWS-KENT Publishing Co., Boston, MA. 191 pp.

Manuwal, D. A., and H. R. Carter. 2001. Natural history of the Common Murre (*Uria aalge californica*). Biology and conservation of the Common Murre in California, Oregon, Washington, and British Columbia. Vol.1: Natural history and population trends (D.A. Manuwal, H.R. Carter, and T.S. Zimmerman, Eds.) U.S. Geol. Surv., Info. Tech. Rep. USGS/BRD/ITR-2000-0012. Washington, D.C. Pp. 1-33.

Mantua, N. J. and S.R. Hare. 2002. The Pacific Decadal Oscillation. Progr Oceanogr Vol. 58, pp. 35-44.

McChesney, G.J., H.R. Carter, and M.W. Parker. 2000. Nesting of Ashy Storm-Petrels and Cassin's Auklets in Monterey County, California. Western Birds 31: 178-183.

MMS (Minerals Management Service). 2001. Marine Mammal and Seabird Computer Database Analysis System Washington, Oregon and California, 1975-1997 (MMS-CDAS, version 2.1). Prepared by Ecological Consulting, Inc. (now R.G. Ford and Consulting Co.), Portland, Oregon for the Minerals Management Service, Pacific OCS Region, Order No.1435-01-97-PO-4206.

Oedekoven, C.S. D.G. Ainley and L.B. Spear. 2001. Variable responses of seabirds to change in marine climate : California Current, 1985-1994. Mar. Ecol. Progr. Ser. Vol. 212, pp. 265-281.

Section 2.2: BIOGEOGRAPHY OF MARINE BIRDS

Philbrick, V.A., P.C. Fiedler, L.T. Ballance, and D.A. Demer. 2003. Report of ecosystem studies conducted during the 2001 Oregon, California, and Washington (ORCAWALE) marine mammal survey on the research vessels David Starr Jordan and McArthur. U.S. Department of Commerce. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-349. Available from <http://swfsc.nmfs.noaa.gov/PRD/ecology/ecology.html>

Pyle, P. and R.P. Henderson. 1991. The birds of Southeast Farallon Island: Occurrence and seasonal distribution of migratory species. West. Birds Vol. 22, pp. 41-84.

Schwing, F. B., Murphree, T., deWitt, L., Green, P. M., 2002. The evolution of oceanic and atmospheric anomalies in the northeast Pacific during the El Niño and La Niña events of 1995-2001. Progress in Oceanography 54, 459-491.

Schwing, F.B. and C.S. Moore. 2000. A year without summer for California, or a harbinger of a climate shift? Trans., Amer. Geophys. U., Vol. 81(27), p. 301.

Schwing, F.B., T.L. Hayward, K.M. Sakuma, T. Murphree, A.S. Mascarenas Jr., S.I. Larios Castillo, A.W. Mantyla, S.L. Cummings, F.P. Chavez, D.G. Ainley and K. Baltz. 1997. The state of the California Current, 1996-1997: mixed signals from the tropics. Calif. Coop. Ocean. Fish. Investig., Repts., Vol. 38, pp. 22-48.

Seber, G. A. F. 1977. Linear regression analysis. John Wiley and Sons, New York. 171 pp.

Shannon, C.E. and W.W. Weaver. 1949. The Mathematical Theory of Communication. Univ. Illinois Press, Urbana. 90 pp.

Spear, L.B. and D.G. Ainley. 1999. Migration routes of Sooty Shearwaters in the Pacific Ocean. Condor, Vol. 101, pp. 205-218.

Sydeman, W.J., N. Nur, E.B. McLaren, and G.J. McChesney. 1998. Status and trends of the Ashy Storm-petrel on Southeast Farallon Island, California, based on capture-recapture analyses. Condor, Vol. 100, pp. 438-447.

Sydeman, W.J., K.A. Hobson, P. Pyle, and E.B. McLaren. 1997. Trophic relationships among seabirds in central California: combined stable isotope and conventional dietary approach. Condor, Vol. 99, pp. 327-336.

Thayer, J.A., and W.J. Sydeman. 2002. Breeding biology and ecology of Rhinoceros Auklets, *Cerorhinca monocerata*, on Año Nuevo Island, California, 2002. Unpublished PRBO report, Stinson Beach, CA.

Thayer, J.A. and W.J. Sydeman. 2002. Population and productivity studies of Año Nuevo seabirds. Unpublished PRBO report, Stinson Beach, CA.

Trenberth, K. E. 1997. The definition of El Niño. Bull. Amer. Meteorol. Soc. 78: 2771-2777.
Veit, R.R., J.A. McGowan, D.G. Ainley T.R. Wahl and P. Pyle. 1997. Apex marine predator declines 90% in association with changing oceanic climate. Global Change Biol., Vol. 3, pp. 23-28.

Warzybok, P.M., R.W. Bradley, and W.J. Sydeman. 2002. Population size and reproductive success of seabirds on Southeast Farallon Island, 2002. Unpublished Report. PRBO Conservation Science, Stinson Beach, CA.

Whitworth D.L., H.R. Carter, R.J. Young, G.J. McChesney, M. Hester and S. Allen. 2002. Status and distribution of the Ashy Storm-petrel (*Oceanodroma homochroa*) at Point Reyes National Seashore, California, in 2001. Unpubl. Rpt, Humboldt State University, Dept Wildlife, Arcata. 15 pp

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

INTRODUCTION

The California Current passes south through the study area off north/central California, which, along with areas of strong coastal upwelling, makes this area one of the most productive ocean systems in the world (Glantz and Thompson, 1981). Because of this productive environment, the study area contains a rich fauna of marine mammals, as evidenced in marine mammal abundance and richness.

In addition to many marine mammal species that live here year-round and use the region's coasts and islands for breeding and hauling out, the community of seasonal residents and migrants is even more robust. Central California is the destination for many marine mammal species seeking productive feeding areas and acceptable habitat in which to spend their nonbreeding periods, providing evidence of the region's trophic richness. Over 29 species of marine mammals occur in the study area off north/central California; over 22 cetaceans (whales, dolphins, and porpoises), six pinnipeds (seals and sea lions), and one fissiped species (the sea otter).

The objectives of this assessment were to: 1) identify spatial and temporal distributions and patterns for marine mammals that occur in ocean waters off north/central California between Point Arena (38.91°N) and Point Sal (34.90°N); 2) identify important areas and time periods associated with higher concentrations of these species; and 3) identify important data and information gaps observed as a result of this analysis. In this analysis, 'important' season or area refers to those having relatively higher concentrations of a particular species; in Phase II diversity may also be considered.

Preliminary Results. Summarized below are the spatial and temporal occurrence patterns of data for 13 species that regularly occur in marine waters off north/central California. The results of this marine mammal assessment are **preliminary** (Phase I) and feature highlights of work in progress. Due to



the difficulty in obtaining adequate distributional data sets and the complexity of combining available marine mammal data sets, maps for only 13 species were completed in Phase 1, and are included in this document. These maps are referred to as CDAS maps, and represent a compilation of data sets from 1980 through 2001, as described below. Also included in this document and on the CDROM are sighting and effort maps for 16 marine mammals from a single data set (the marine mammal stock assessment surveys from NOAA's Southwest Fisheries Science Center (SWFSC)). These data will likely be incorporated into Phase II of the analysis.

Additional data compilation, data analysis and expert review are needed to complete the final analyses of marine mammals occurrences in the study area. More complete results will be presented in a final report in Phase II of this project. Additional products planned for Phase II are listed at the end of this section.

DATA AND ANALYSES

Overview of Map Development and Analysis Process To Date.

The methods used in each survey were different, and because of this, careful consideration and correction are required to merge the data sets in a meaningful and scientifically acceptable way. Data preparation for the mammal analyses included the following steps: species and study area selection, data set identification and collection, data corrections, data conversion into common units, organizing the data into 10'x10' cells or leaving them as sightings and effort, and map development. For species present in sufficient numbers, seasonal density maps were developed, and for infrequently sighted species, sighting and effort maps were developed. CDAS maps were created for 13 species. The original draft maps were reviewed at an expert workshop in October 2002; there it was determined that additional data, corrections and analyses were required to improve the mammal maps; this work will be done in Phase II of this project. Some revisions have been made to the maps and text of this document since its draft release in April 2003.

Species Selected for Analysis. Selection criteria for marine mammal species included in this assessment were: 1) the species distribution includes the study area, and 2) survey data for the species was available

in a useable format. Some species of marine mammals are infrequently sighted and their distributions are therefore difficult to map. In addition, some data sets were unavailable at the time of the analysis. Over the past few months, additional data sets have been made available, and these will be added in Phase II. Improvements and updates are planned for the at-sea maps, as well as for the haulout and rookery maps, if funding is made available.

Table 22 is a list of marine mammal species that were considered for this analysis; density maps were developed for eight species in MMS-CDAS (MMS, 2001) a data display system developed by R.G. Ford Consulting Co. for the Minerals Management Service. Sightings maps were developed in CDAS for an additional four species. Maps of sea otter counts and pinniped haulouts and rookeries were also developed. Also included in this document are maps for three species from

NOAA's Southwest Fisheries Science Center (SWFSC). These maps are included to illustrate one of the data sets that will likely be incorporated into the mammal map analysis in Phase II. SWFSC maps for an additional 13 species are included on the CD-ROM. Plans for Phase II include the following: 1) acquire the additional available data sets; 2) correct the data sets for species' sightability, detectability and other factors; and 3) develop composite maps for about 23 species, singly or in combination.

About the Literature and Survey Data Used in this Assessment. This assessment is based on the efforts of individual researchers to study marine mammal spatial and temporal patterns, federal and state government efforts to assess stock size and the potential biological impacts of oil development, and state government efforts to respond to oil spills.

Table 22. Marine mammal species included in this assessment and map types developed for them (Phase I and Phase II)

Common Name	Scientific Name	Order/Suborder	Family	No. of Draft CDAS Maps, Phase I	No. of SWFSC Maps, Phase I	No. of Maps Planned for Phase II
Fissiped						
Southern sea otter	<i>Enhydra lutris nereis</i>	Carnivora/(none)	Mustelidae	1		1
Pinnipeds						
California sea lion	<i>Zalophus californianus</i>	Carnivora/Pinnipedia	Otariidae	2		1
Steller sea lion	<i>Eumetopias jubatus</i>	Carnivora/Pinnipedia	Otariidae	1		1
Northern fur seal	<i>Callorhinus ursinus</i>	Carnivora/Pinnipedia	Otariidae	1		1
Harbor seal	<i>Phoca vitulina richardsi</i>	Carnivora/Pinnipedia	Phocidae	1		1
Northern elephant seal	<i>Mirounga angustirostris</i>	Carnivora/Pinnipedia	Phocidae	1		1
Cetaceans						
Dall's porpoise	<i>Phocoenoides dalli</i>	Cetacea/Odontoceti	Phocoenidae	1	1	1
Harbor porpoise (stocks: Northern CA, San Francisco/Russian River, Monterey Bay)	<i>Phocoena phocoena</i>	Cetacea/Odontoceti	Phocoenidae		1	1?
Pacific white-sided dolphin	<i>Lagenorhynchus obliquidens</i>	Cetacea/Odontoceti	Delphinidae	1	1	1
Risso's dolphin	<i>Grampus griseus</i>	Cetacea/Odontoceti	Delphinidae	1	1	1
Bottlenose dolphin (California coastal stock)	<i>Tursiops truncatus</i>	Cetacea/Odontoceti	Delphinidae		1	1?
Short-beaked common dolphin	<i>Delphinus delphis</i>	Cetacea/Odontoceti	Delphinidae		1	1
Northern right whale dolphin	<i>Lissodelphis borealis</i>	Cetacea/Odontoceti	Delphinidae	1	1	1
Killer whale	<i>Orcinus orca</i>	Cetacea/Odontoceti	Delphinidae		1	1?
Baird's beaked whale	<i>Berardius bairdii</i>	Cetacea/Odontoceti	Ziphiidae		1	1?
Cuvier's beaked whale	<i>Ziphius cavirostris</i>	Cetacea/Odontoceti	Ziphiidae		1	1?
Beaked whales (Mesoplodonts)	<i>Mesoplodon spp.</i>	Cetacea/Odontoceti	Ziphiidae		1	1?
Sperm whale	<i>Physeter macrocephalus</i>	Cetacea/Odontoceti	Physeteridae		1	1?
Blue whale	<i>Balaenoptera musculus</i>	Cetacea/Mysticeti	Balaenopteridae	1	1	1
Humpback whale	<i>Megaptera novaeangliae</i>	Cetacea/Mysticeti	Balaenopteridae	1	1	1
Fin whale	<i>Balaenoptera physalus</i>	Cetacea/Mysticeti	Balaenopteridae		1	1?
Minke whale	<i>Balaenoptera acutorostrata</i>	Cetacea/Mysticeti	Balaenopteridae		1	1?
Gray whale	<i>Eschrichtius robustus</i>	Cetacea/Mysticeti	Eschrichtiidae	1		1
MAP TOTALS				14	16	14-23

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

Table 23. Summary of at-sea data sets used in the preliminary marine mammal analyses.

Data Set	Principal Investigator	Vessel Name & Platform Height	Habitat Covered ²	Years	Ocean Seasons Covered	Total Transect Width: Pinnipeds	Total Transect Width: Cetaceans
MMS High-Altitude Aerial Surveys	Dohl	Pembroke, 270m	Surface survey of the shelf, slope & deep ocean beyond	1980-1983	All three seasons	N/A	harbor porpoise, 254m; great whales, 1130m; all others, 885m
MMS Low-Altitude Aerial Surveys	Bonnell	Pembroke, 62m	Surface survey of the shelf, slope & deep ocean beyond	1980-1983	All three seasons	109m	109m
EPOCS Shipboard Surveys	Ainley	Surveyor, 12m, Discoverer, Oceano-grapher, 15m	Surface survey of the deep ocean	1984-1994	All three seasons	300-600m	800m
CA Seabird Ecology Low-Altitude Aerial Surveys	Briggs	Partenavia, 62m	Surface survey of shelf and slope	1985	Mainly Upwelling	50m	50m
NMFS Midwater Trawls for Juv. Rockfish: Ship Surveys	Ainley	David Starr Jordan, 10m	Surface survey of shelf and slope to 3000 m	1985-2001	Mainly Upwelling	300m	800m
OSPR Low Altitude Aerial Surveys	Bonnell	Partenavia, 62m	Surface survey of shelf and slope	1994-1998, 2001	All three seasons	50m	50m
MMS Santa Barbara Channel Low Altitude Aerial Surveys	Bonnell	Partenavia, 62m	Surface survey of shelf and slope	1995-1997	All three seasons	50m	50m
SF-DODS Shipboard Surveys	Ainley	Point Sur, 8m	Surface survey of shelf and slope to 3000 m	1996-2000	All three seasons	300m	800m

Notes
See additional description of these data sets on the CD for more information on the CDAS data sets.
Data from the marine mammal stock assessment of NOAA's SWFSC were not included in the preliminary CDAS assessment.

Related Literature. The at-sea distribution and abundance of marine mammals within the study area has been described in many publications, some of which include the following: Bonnell et al. (1983), Dohl et al. (1983), Calambokidis et al (1988, 1990, 1996), and Allen (1994). Numerous marine mammal stock assessment studies have been conducted by the Southwest Fisheries Science Center, LaJolla, CA (NMFS/ SWFSC ship surveys): Barlow (1988, 1995), Barlow and Forney (1994), Barlow and Gerrodette (1996), and Forney and Barlow (1998). A few ecosystem studies of marine mammals in this region have also been conducted by Schoenherr (1991), Black (1994), Kieckhefer (1992), Croll et al. (1998), Forney and Barlow 1998, Forney 2000, Benson et al. (2002) and Keiper et al. (*In Review*).

The Data Sets. The ship and aerial strip transect data used in this assessment were collected from 1980-2001 and ranged from Point Arena south to Point Sal, and offshore to the extent of data availability. Estuaries were not part of the GIS study area, but coastal haulouts and rookeries, when available, were mapped to provide a more complete view of important areas for pinniped species. See Table 23 for additional information on the data.

Data Synthesis.
Summarizing Transect Data into Grid Cells for CDAS Maps. The above data sets were processed to compensate and correct for differences in survey methodology, including platform type (ship or aerial) and transect width, among the various studies.

Because wind speed affects detection of marine mammals, data collected when wind speed exceeded 25 kt were excluded. Data were allocated into 10' x 10' cells (i.e., 10-minute latitude by 10-minute longitude cells). All aerial data were continuous; each ship-based data set was converted separately into a continuous transect format to the extent possible. The continuous aerial data were binned into the appropriate cell. For the SF-DODS and EPOCS studies, and the Rockfish Assessment cruises prior to 1997, the beginning position, ship heading, and speed were used to compute the end position of each 2-4 km continuous transect. From this, a midpoint of the transect was determined. As times of observations were not available, the position of the midpoint was used to select the cell to which the survey effort was assigned. If this midpoint fell on a cell boundary, it was assigned to the cell to the north or west. To maintain the correspondence between effort and mammal observations, observations were also assigned to the transect midpoints. For the Rockfish Assessment Cruises from 1997 onward, effort was assigned to the cells through which the vessel passed based on the proportion of trackline that fell within each cell, and observations were interpolated along the cruise track according to the time of each observation.

Data Analysis.
Effort Summary. For all surveys, 132,521 kilometers of trackline (pinnipeds and cetaceans) and 78,486 kilometers of additional trackline (cetaceans only) were analyzed (Table 24). A total of 3,459 observations of 7,039 pinnipeds and 2,313 observations of 69,286 cetaceans were included in analyzed data. Survey effort used in this assessment for pinnipeds and cetaceans are summarized as maps in Figure 61.

Organizing Data into Ocean Seasons. Effort and species data were organized and mapped into three distinct ocean seasons (Bolin and Abott 1963): Upwelling, Oceanic, and



Davidson Current, because ocean conditions differ distinctly among them and are known to affect the biota of the California Current (e.g. Ainley 1976, Briggs et al. 1987). As there is significant interannual variation in the actual duration of these seasons, the following dates were 'defined' for each season for purposes of analysis: Upwelling Season is 15 March-14 August, Oceanic Season is 15 August-14 November, and Davidson Current Season is 15 November-14 March.

As evident in Table 24, the Upwelling Season had the greatest amount of survey effort, followed by the Davidson Current Season. The Oceanic Season had the lowest effort. Unlike the other seasons, the Oceanic Season had no data from the 1980s. Because of the variation in effort coverage across space and time (and methods, as well as many other factors), interpretation of the data requires careful consideration.

Table 24. Summary of combined data set effort at sea for mammals, by ocean season.

Ocean Season	Dates Used for Each Ocean Season	Number of Months	Years Included	Taxa	Kilometers of Trackline Surveyed	Number of Visits	Number of 10' Cells Sampled
Upwelling	15 Mar-14 Aug	5	1980-1982, 1985-2001	<i>Pinnipeds:</i>	63,262	10,902	283
				<i>Cetaceans:</i>	96,978	15,280	317
Oceanic	15 Aug-14 Nov	3	1980-1982, 1991, 1994-2001	<i>Pinnipeds:</i>	30,443	4270	263
				<i>Cetaceans:</i>	49,981	6821	322
Davidson Current	15 Nov-14 Mar	4	1980-1986, 1991-2001	<i>Pinnipeds:</i>	38,816	5594	360
				<i>Cetaceans:</i>	64,048	8897	383
TOTAL	1 Jan-31 Dec	12	1980-2001	<i>Pinnipeds:</i>	132,521	20,766	395
				<i>Cetaceans:</i>	211,007	30,998	416

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

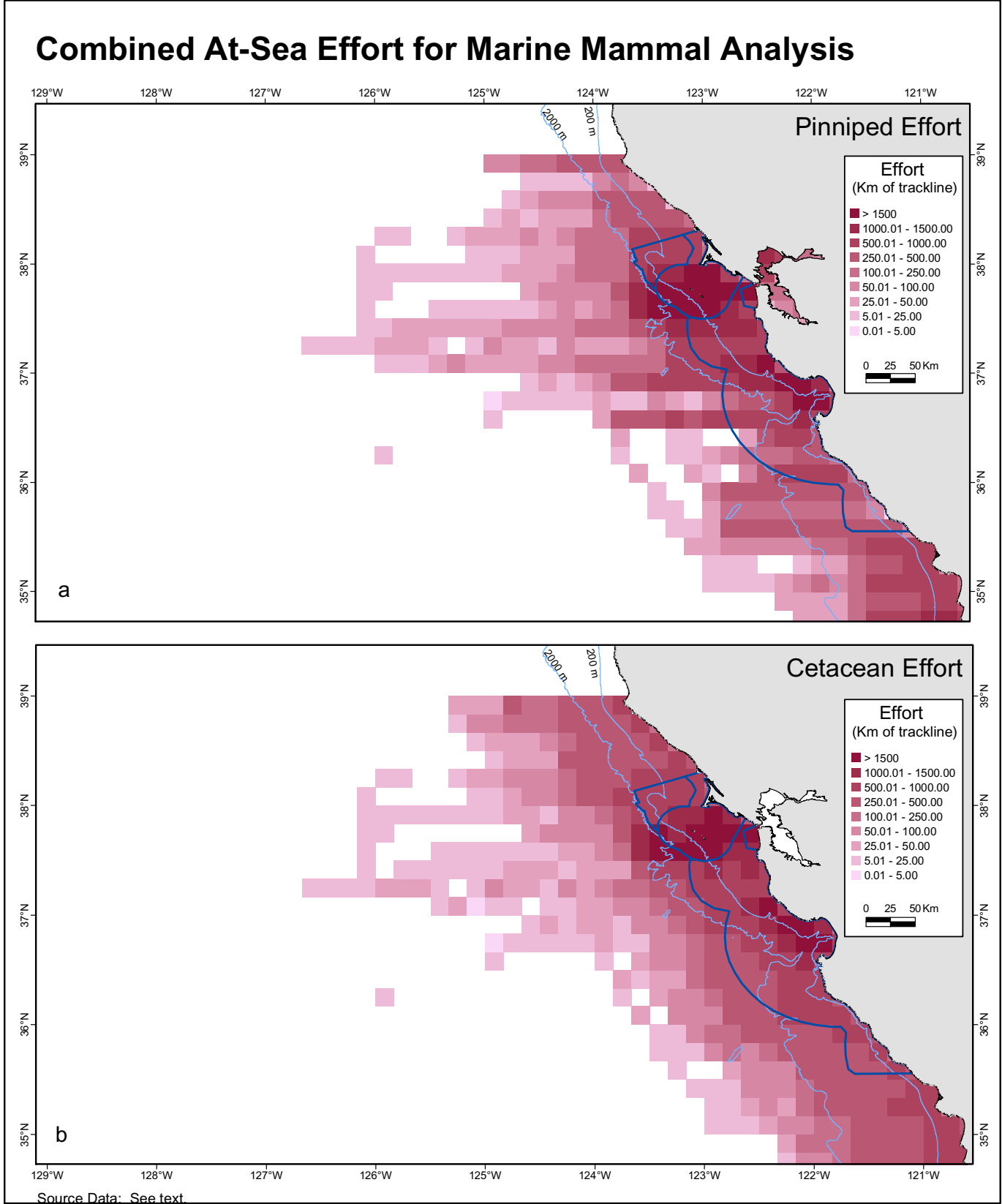


Figure 61. Total at-sea survey effort for marine mammal analyses.

Calculating Density and Developing Seasonal Density CDAS Maps. From the digitized survey data, we mapped the distribution of effort and of species observations into a grid of 10' by 10' cells, using the MMS-CDAS mapping system (MMS, 2001). The larger cell size was determined to be more meaningful by experts at a preliminary map/data review session.

The species data were first transformed into densities on the basis of strip widths (which varied by ship or aerial platform, depending on speed and height above water; see Table 23). The number of individuals of each species seen was then divided by area surveyed to estimate density in each cell for that data set. For construction of density plots, if a cell was censused in other years or the same year by another survey, densities in cells were averaged and weighted according to effort. These maps display observed densities; in Phase II these densities will be corrected to account for additional factors such as sightability.

Seasonal High Use Areas for Individual Species. The purpose of the seasonal high use maps is to provide a summary map for a species' spatial patterns. These maps were developed for mammal species with density data, with the seasonal density data binned into 10' x 10' cells for each species or species group. Non-zero cells were then ranked and those in the top 20 percent were selected and defined as seasonal high use areas. Cells were then mapped with color corresponding to the number of ocean seasons of high use. The index is therefore sensitive to cells that were not sampled in any one of the three seasons, causing a downward bias in the index. Use of a 10'x10' cell size greatly reduces the magnitude of this bias.

Cells in which there was effort but animals were not observed, and cells where sightings occurred but were never high use areas, were also provided.

Developing Sighting and Effort CDAS Maps for Infrequently Sighted Species. Where sightings were too few to warrant seasonal density maps, observations were mapped as point locations. For context, overall survey effort is also presented. This display method was chosen in response to comments by expert reviewers at the October 2002 workshop and in view of the low numbers of sightings of certain species.

Preliminary Rookeries and Haulouts by Species. Pinniped rookeries and haulouts are monitored and surveyed by a variety of institutions and individuals. Recent data (varying by species, but generally from 1998-2002) were used to represent locations of rookeries and haulout sites for five pinniped species. In Phase II, additional information on harbor seal pupping sites

will be added and an overall rookery and haulout map for the pinnipeds will be developed.

ANALYTICAL MAP PRODUCTS

A series of over 50 preliminary maps (41 CDAS maps and 12 SWFSC maps) and related results are presented in this section; additional SWFSC maps for 13 mammal species/species groups are included on the CD-ROM. These preliminary maps will be finalized and included in a Phase II report.

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

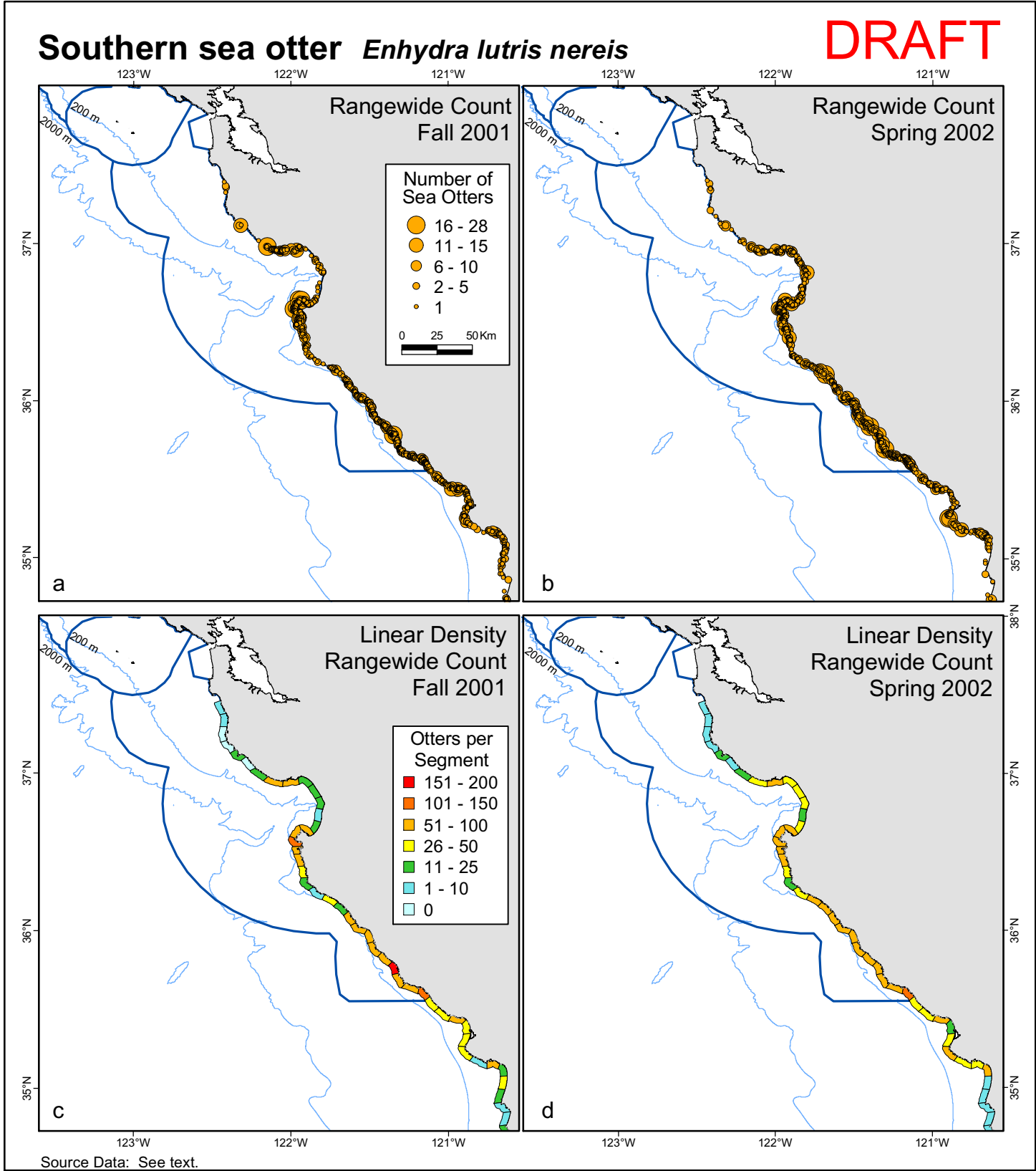


Figure 62. Maps for southern sea otter: rangewide count and linear density, fall 2001 and spring 2002.

ABOUT THESE MAPS

Maps 62a and b display the locations of groups of southern sea otters during the Fall 2001 and Spring 2002 rangewide counts. Maps 62c and d summarize these rangewide count data into coastal strips approximately 10km in length, in order to display linear densities along the shore. The northern extent of the data is south of Half Moon Bay; sea otters are also present to the south of the mapped area.

DATA SOURCES

Data were collected by wildlife biologists from the U.S. Department of the Interior (currently the USGS Biological Resources Division), California Department of Fish and Game, the Monterey Bay Aquarium, and trained volunteers during semi-annual rangewide counts in Fall 2001 and Spring 2002. The Fall 2001 count was conducted during the period 4-20 November 2001, the Spring 2002 count was conducted during the period 5-22 May 2002. The data set was provided by Mike Kenner, UCSC but is sourced to USGS; contact Brian Hatfield for more information.

METHODS

The original data were entered from hand marked maps into a custom designed digitizing program which assigned coordinates to each observed sea otter group. Positions of animals toward the ends of the range and in Elkhorn Slough were not assigned coordinates by this program. Each group was also assigned to an ATOS (As The Otter Swims) number, which are numbers approximately 0.5 km apart along a smoothed 5 fathom contour line along the coast from Golden Gate to approximately Santa Barbara. These numbers were used to get approximate positions for otters without assigned coordinates.

A series of coastal segments approximately 2 km in width was created for display purposes. Each segment was approximately 10 km in length; divisions were based on the ATOS numbers described above. Twenty ATOS numbers approximately 500m apart were included in each segment. The coordinates of each otter group were used to place it within a particular segment, and the otters in each segment were summed. This provides an estimate of linear density (otters per segment or otters per 10km) since the segments were approximately 10km in length.

RESULTS AND DISCUSSION

The southern sea otter (*Enhydra lutris nereis*) is one of three subspecies: southern (*E.l.nereis*), northern (*E.l.kenyonii*), and Russian (*E.l.lutris*). The southern sea otter is listed as threatened under the Federal Endangered Species Act, and depleted under the Marine Mammal Protection Act (MMPA). Under California Fish and Game Code, the southern sea otter is listed as a “fully protected” species. The southern sea otter generally inhabits the near-shore waters of the central California coast,

from Half Moon Bay to Goleta, just south of Point Conception with uncommon sightings of animals beyond these areas (pers. comm. B. Hatfield); the distribution of otters along the south end has been highly variable since the expansion of the sea otter range south of Point Conception (pers.comm. M.Harris). In the study area, sightings have occurred as far north as Point Reyes (Point Reyes Headlands, Double Point, Duxbury Reef; not shown on map; pers.comm. S. Allen). Sea otters occur along rocky shorelines with kelp beds (but also in open water habitats, sandy/soft bottom areas, and tidal estuaries) and in depths of water about 20-40 m (some to 60 m, and rarely to 100 m; M. Kenner pers. comm).

Overall, numbers of otters per segment were greater in the southern portion of the Monterey Bay National Marine Sanctuary. In the census of Fall 2001 (map a), greater numbers of otters per segment occurred along the Carmel coast and from Piedras Blancas south to Point San Luis. Seasonal changes in abundance and distribution of sea otters are believed to be affected by male movements during the period when most breeding occurs (June/July through October/November) when they move from the periphery of the range toward the center of the range in search of estrous females (Bonnell et al., 1983). From December to April, many males migrate to the range peripheries, perhaps in search of more abundant prey (M.Harris pers. comm.). However, this is not evident in the maps. Seasonal changes also are affected by factors such as weather, sea conditions and abundance of kelp canopy (see Reidman and Estes, 1990).

From 1983 until the mid 1990’s, trends in spring southern sea otter counts indicated sea otters increased steadily; in the mid-to late 1990’s, sea otter numbers declined (USFWS, 2000) and have since remained relatively constant (pers.comm. B. Hatfield). Sea otter count data is used as an index to assess trends in the population dynamics, not as a population estimate (pers.comm. M.Harris). The 2002 spring count was 1% below the 2001 count, from 2161 otters in 2001 to 2139 in 2002. The 2001 count was 6.7% below counts from the previous year (USGS 2002). Due to its small population size, the southern sea otter population is especially vulnerable to human disturbance, competition with fisheries, and pollution, including the threat of a major oil spill. The lack of population growth and recent decline coincides with an increase in mortality (e.g., infectious diseases, white shark attacks) as indicated by the number of beach-cast sea otter carcasses (Estes et al., 2003). Otters near heavy freshwater flows are three times more likely to have been infected by *Toxoplasma gondii*, a protozoan parasite caused by parasite eggs in cat droppings (see Miller et al., 2002).

Southern sea otters are key predators of benthic species (e.g. sea urchins, sea stars, mussels, clams, abalone, crabs) and octopus (see Riedman and Estes, 1990).

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

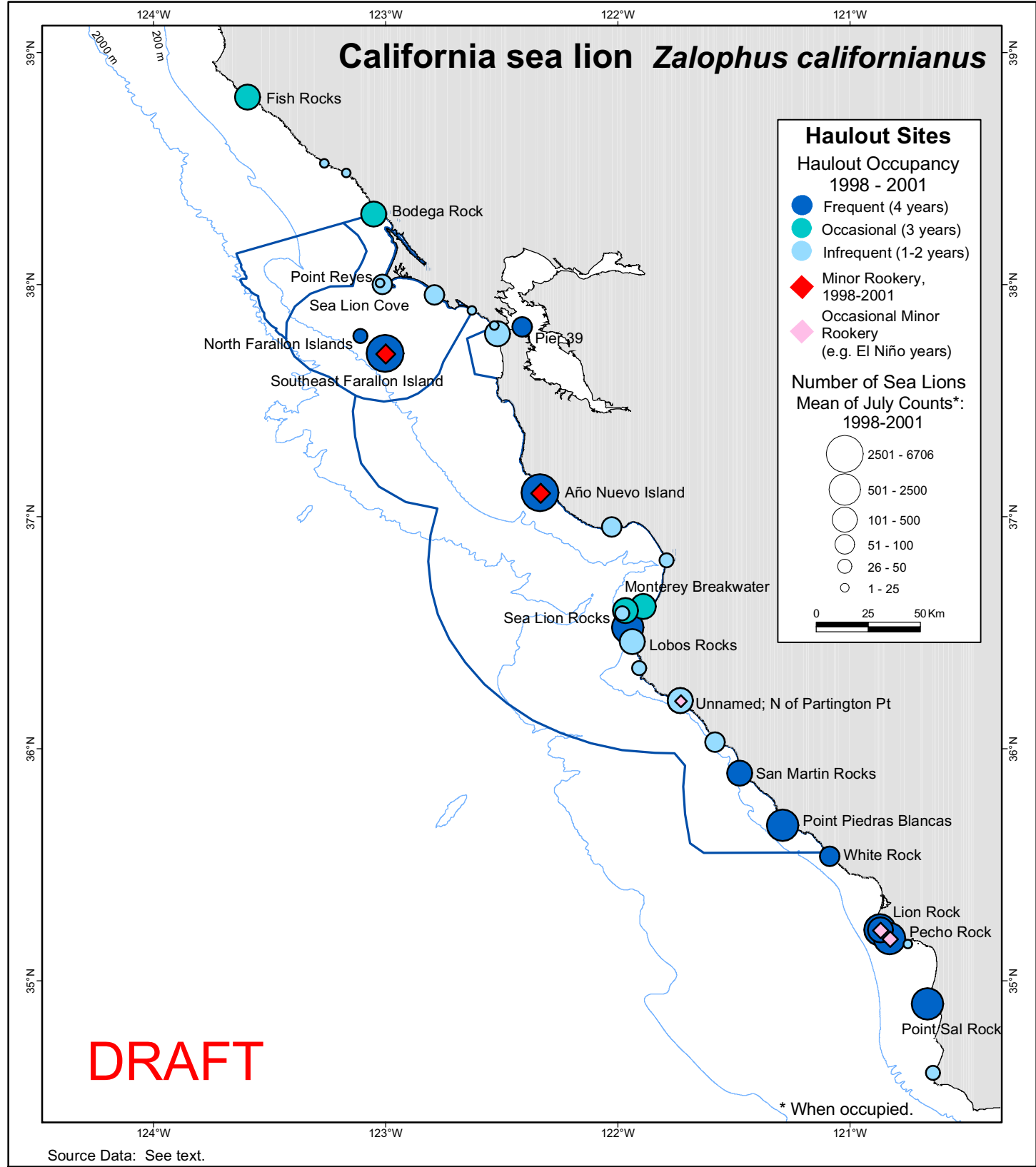


Figure 63. Map for California sea lion: haulouts and rookeries.

ABOUT THIS MAP

Figure 63 summarizes information on California sea lion haulouts and rookeries in the study area based on number of animals, frequency of use, and rookery status.

DATA

Haulout data and rookery information are from aerial counts (July, 1998-2002) provided by Mark Lowry of the NMFS' Southwest Fisheries Science Center.

METHODS

Haulout locations were mapped using coordinates included in the files from Mark Lowry, SWFSC. Data from July counts in four years, 1998-2002, were used to calculate frequency of use for each haulout location and mean number of animals using each location when that location was occupied. Rookery status was determined by the inclusion of pups in the counts. Pups were observed in all years at two sites, while three sites had pups only in 1998, an El Niño year.

RESULTS AND DISCUSSION

Haulout sites for the California sea lion are located along the coast from Fish Rocks (just south of Point Arena) to the south, at Point Sal Rock, and inside San Francisco Bay (Pier 39). Minor rookeries are located on the Southeast Farallon Island and Año Nuevo Island.

Periods of unusually warm ocean waters associated with El Niño oceanographic conditions affect pup production (i.e., fewer pups are born) and result in higher mortality rates for pups and juveniles. During the El Niño periods of 1983, 1992, and 1998, pup production decreased by 35, 27, and 64%, respectively at rookeries in southern California (SWFSC 2001).

Similar to at-sea occurrence patterns, haulout patterns and rookery locations also change during warmer water periods. For example, rookery locations during the strong El Niño of 1998 (shown on the map) included the rookeries at the Farallones and Año Nuevo as well as additional rookeries located near Partington Point, and Lion, Pecho, and Pup Rocks located to the south of the Monterey Bay National Marine Sanctuary. Haul-out patterns at the Farallon Islands and Point Reyes National Seashore also changed, indicated by an influx of immatures (Sydeman and Allen, 1999; S. Allen pers.comm.).

Greater numbers of California sea lions in the study area during El Niño events likely reflected a greater than usual northward migration in response to a reduction of food resources near southern breeding grounds.

California sea lions feed on a diversity of fish (e.g., Pacific hake, northern anchovy, Pacific sardine, herring, rockfish, salmon, steelhead) and invertebrates (e.g., squid and octopus) (Weise, 2000; see also Riedman 1990).



Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

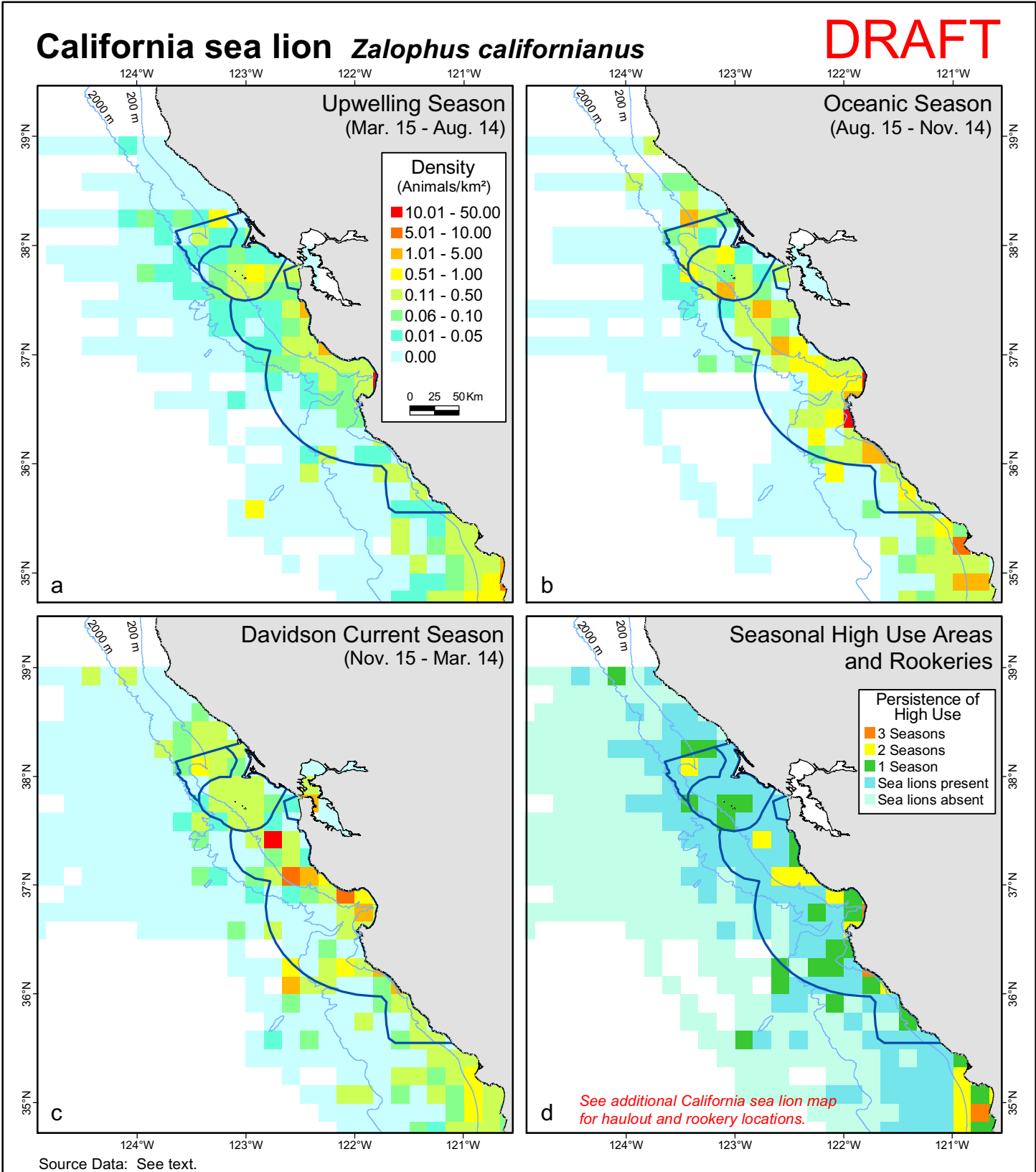


Figure 64. Maps for California sea lion: seasonal at-sea densities, high use areas, and rookeries.

ABOUT THESE MAPS

Figures 64a, b, and c show the at-sea density (animals/km²) of California sea lions in the Upwelling, Oceanic, and Davidson Current seasons, displayed in 10'x10' cells. Densities are based on combined data of several studies; see "Methods" and "Data Sources" sections. The color and mapping intervals were customized to show the most structure and to highlight significant areas, while allowing comparisons among marine mammal species. Cells that were surveyed but which had no California sea lions have a density of zero; unsurveyed areas appear white. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200 m and 2,000 m isobaths are also shown in blue.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence in the study area, map d shows seasonal high use areas, displayed in 10'x10' cells. This map provides a further synthesis of densities presented in maps a, b and c (see "Methods" section for details), and portrays the relative importance of various areas to the species. Areas with consistent high use are highlighted on this map. To provide a relative reference for the "high use" areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there), or present but at lesser concentrations in any particular season.

DATA SOURCES

At-sea densities for the California sea lion are based on data from seven survey programs conducted in 1980-2001. These data were combined using CDAS software into the MMS-CDAS data system (MMS, 2001), developed for Minerals Management Service and expanded for this project. Of the data sets on the original CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program was still ongoing and data from recent years were added to this data set. In addition, data from three ship-based survey programs were converted to a compatible format for analysis. See section text for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (MMS, 2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDF&G-OSPR), unpublished data. Early data were collected using methods described by Bonnell et al. (1983); more recent data were collected using updated technology but with the same general method. Data sources for ship-based survey data include David Ainley, unpublished data (see Oedekoven et al., 2001 for details on methods). Although the at-sea data span the years 1980-2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001.

For the Oceanic Season, data are from 1980-1982, 1991, and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001. The rookery and haulout counts are shown as a general range, based on counts of all animals (pups and adults) in three years, 1999-2001.

METHODS

At-sea densities are the result of a synthesis of data from seven shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources" section). Pinniped observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into 10'x10' cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of cetaceans of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was censused more than once, densities were averaged, with adjustment made for effort.

Note that these maps represent either sighting locations or densities that used survey strip widths relative to each survey platform (e.g., plane, ship); density was calculated on the basis of the number of animals sighted and area surveyed. The data have only been corrected to normalize for survey effort and to exclude observations with winds greater than 25 knots (smaller or less obvious species are often less detectable even at wind speeds of less than 25 knots). Additional corrections are planned for Phase 2 of this project and are briefly discussed below.

For example, no adjustments or corrections have been made to account for differences in marine mammal detectability among species and differential probability of detecting animals from aerial and shipboard platforms. Individual body size, group size, and species-specific behaviors, such as proportion of time spent submerged, are all factors known to affect detection and hence, observed distribution and density estimates as well. Because of the very different attributes of aerial and shipboard platforms, these factors, and the associated adjustments for observations, vary among the studies.

Map d was developed using the same approach as for maps a, b and c. For each season, the cells with densities in the top 20% of non-zero values were designated "high use" for that season.

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

Cells were scored for “high use” in one, two, or three seasons and are depicted by color. To provide a relative reference for the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season). Further detail on methods is provided in the Data and Analysis section.

RESULTS AND DISCUSSION

The California sea lion (*Z.c.californianus*) is subdivided into three stocks (U.S., Western Baja California, and Gulf of California); the United States stock begins at the U.S. Mexico border and extends northward into Canada (Carretta et al. 2001). The breeding areas are on islands located in southern California, western Baja California, and the Gulf of California. In the study area, a small number of pups are born on Año Nuevo Island and Southeast Farallon Island; otherwise the central California population is composed of non-breeders. Adult females and immatures remain near the rookeries year-round, whereas adult males (along with most immatures) migrate northward to feeding areas from central California to British Columbia.

In the study area, this species was the most abundant of the pinnipeds (at-sea sightings: n=1,497 individuals: n=4,411) and was widely distributed throughout the shelf and upper slope regions of the three national marine sanctuaries. The seasonal abundance of California sea lions off central California is linked to spring and fall pre- and post-breeding migrations. Densities were greatest during the Oceanic Season (just after breeding) and Davidson Current Season (before the next breeding period) and somewhat lower during the Upwelling Season (breeding period).

Periods of unusually warm ocean waters associated with El Niño oceanographic conditions affect pup production (i.e., fewer pups are born) and result in higher mortality rates for pups and juveniles. During the 1983, 1992, and 1998 El Niño events, pup production decreased by 35, 27, and 64%, respectively, at rookeries in southern California (SWFCS 2001). At-sea distribution patterns were also altered; greater numbers of sea lions were sighted off central California during these warmer periods (see also Bonnell & Ford 1987, Trillmich & Ono 1991, Allen 1994, Keiper 2001, and Keiper et al. In Review.).

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

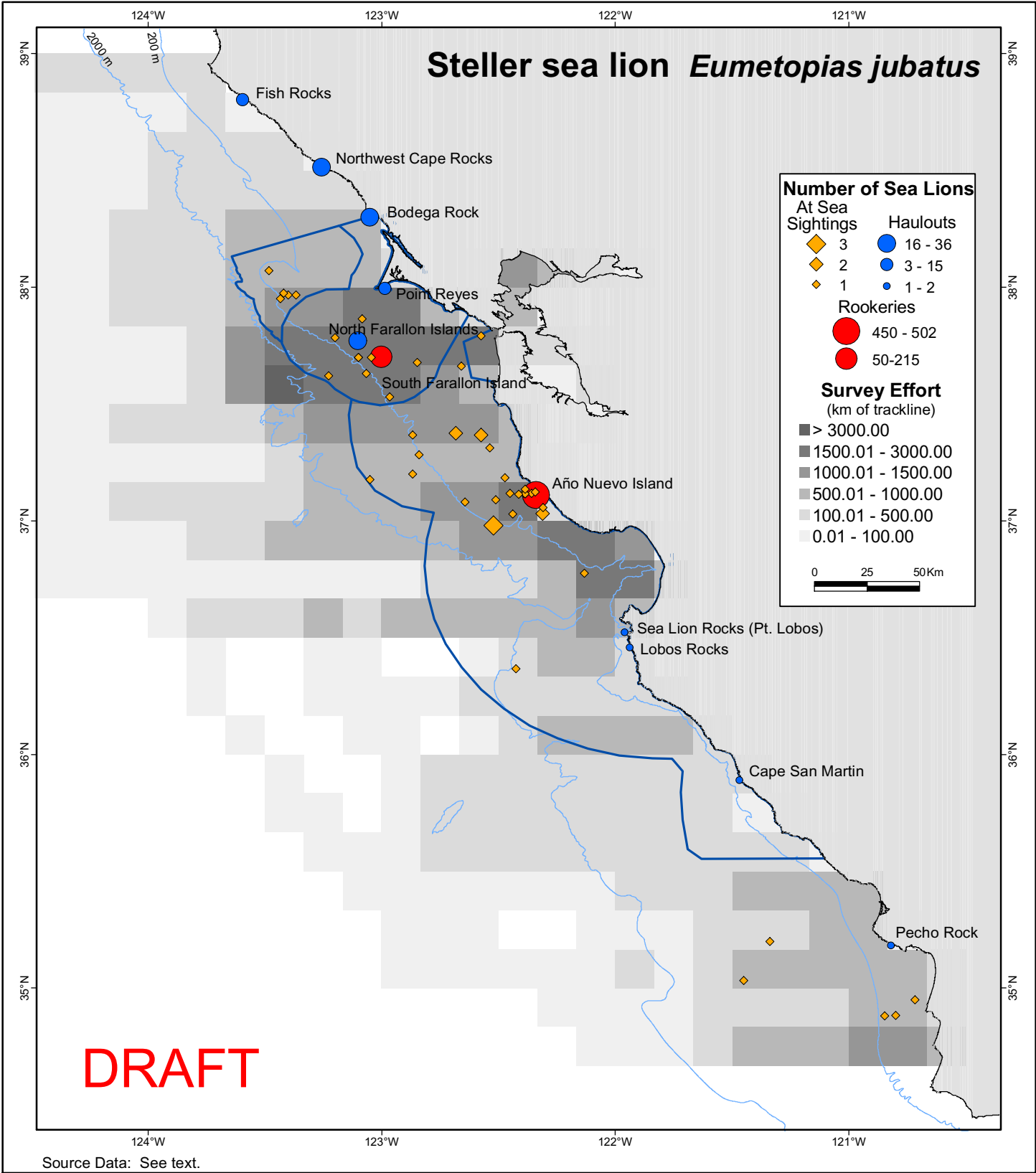


Figure 65. Map for Steller sea lion: at-sea sightings and survey effort, rookeries and haulouts.

ABOUT THIS MAP

Figure 65 shows individual sightings of Steller sea lions at sea along with the locations of haulouts, rookeries, and at-sea effort in the study area. At-sea observations are based on combined data of several studies (see “Methods” and “Data Sources” sections). For context, the amount of combined survey effort (km of trackline) is also shown, summarized in 10’x10’ cells. Haulout locations are based on counts conducted in July 2000. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200 m and 2,000 m isobaths are also shown in blue.

DATA SOURCES

At-sea sightings for the Steller sea lion are based on data from seven survey programs conducted in 1980-2001. These data were combined using CDAS software into the MMS-CDAS data system (MMS, 2001), developed for Minerals Management Service and expanded for this project. Of the data sets on the original CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program was still ongoing and data from recent years were added to this data set. In addition, data from three ship-based survey programs were converted to a compatible format for analysis. See section overview for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (MMS, 2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDFG-OSPR), unpublished data. Early data were collected using methods described by Bonnell et al. (1983); more recent data were collected using updated technology but with the same general method. Data sources for ship-based survey data include David Ainley, unpublished data (see Oedekoven et al., 2001 for details on methods). Although the at-sea data span the years 1980-2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991 and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001. Rookery and haulout data are from Mark Lowry of NMFS’ Southwest Fisheries Science Center. Rookery and haulout data are from Mark Lowry of NMFS’ Southwest Fisheries Science Center. The rookery numbers represent a general range based on counts of all animals (pups and adults) in three years, 1999-2001. The haulout data are from July 2000.

METHODS

The latitude and longitude coordinates of Steller sea lions at sea were used to plot the individual sightings; the coordinates from Mark Lowry were used to plot the haulouts and rookeries. At-sea sightings and effort are the result of a synthesis of data

from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see “Data Sources”). Cetacean observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, effort was mapped into 10’x10’ cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled.

Note that the these maps represent either sighting locations or densities that used survey strip widths relative to each survey platform (e.g., plane, ship); density was calculated on the basis of the number of animals sighted and area surveyed. The data have only been corrected to normalize for survey effort and to exclude observations with winds greater than 25 knots; additional corrections are planned for Phase 2 of this project and are briefly discussed below.

For example, no adjustments/corrections have been made to account for differences in marine mammal detectability among species and differential probability of detecting animals from aerial and shipboard platforms. Individual body size, group size, and species-specific behaviors, such as proportion of time spent submerged, are all factors known to affect detection and hence, observed distribution and density estimates as well. Because of the very different attributes of aerial and shipboard platforms, these factors, and the associated adjustments for observations, vary among the studies.

The data in these maps include wind conditions of up to 25 knots; smaller or less obvious species are often less detectable even at wind speeds of less than 25 knots. The seasonal maps contain different combinations of shipboard and aerial data; therefore the seasonal densities from these platforms may not be directly comparable. A full consideration of these factors, and revised maps, are planned for Phase 2 of this project.

RESULTS AND DISCUSSION

Steller sea lions range from northern Japan, the Aleutian Islands and Gulf of Alaska, south to Año Nuevo Island, California (the southernmost rookery). Steller sea lion females and pups are found at the rookeries year-round, but adult bulls are only at the rookery during the breeding season (mid-May to mid-July). In the study area, the Steller sea lion occurred over the shelf and slope, and, although there were few at-sea sightings in the data set, most occurred in the area between Cordell Bank and Año Nuevo Island.

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

The Steller sea lion population has declined approximately 64% throughout its range (NMFS Biological Opinion, 2000; see also NMFS 1992). Based on distributional data, Steller sea lions are classified into two separate stocks within U.S. waters: 1) the western stock, that includes animals at, and west of, Cape Suckling, Alaska, (classified as endangered); and 2) the eastern stock (including the California population) that includes animals east of Cape Suckling (classified as federally threatened). Greatest concentrations of Steller sea lions occur north of central California, hence, relatively few sightings (n=45 sightings; n=50 individuals) occurred in the study area. Insufficient data precluded mapping the Steller sea lion by seasons.

The breeding season is from mid-May to mid-July. In the study area, rookeries are located at the Farallon Islands (where they breed in small numbers and haul-out in slightly larger numbers throughout the year, USFWS 2000) and at Point Año Nuevo Island (see LeBoeuf et al. 1991). From 1977 to 1996 on the Farallon Islands, adult females present during the breeding season declined by 5.9% and maximum number of pups counted declined significantly (see Hastings and Sydeman 2002). Until the early 1970's, Steller sea lions used to breed at the Point Reyes Headlands but in recent years numbers have been low (fewer than 50; S. Allen pers. comm., 2003). Haulout sites north of San Francisco are located at Fish Rocks, Northwest Cape Rocks, Bodega Rocks, Point Reyes and the Farallon Islands. Another haulout site not on the map is located north of Fort Ross at "Sea Lion Rocks"; maximum counts at this site occur in June (approx. 50) and consist mostly of females with pups of the year (J. Mortenson pers.comm., 2003). Adult males disperse widely during the non-breeding season.

Numbers of Steller sea lions off southern and central California have declined significantly, from 5,000-7,000 non-pups in 1927-1947, to 1,500-2,000 non-pups between 1980-1998 (NMFS Biological Opinion, 2000). Threats to Steller sea lions include incidental take by commercial fisheries, getting shot, entanglement in marine debris, declining trends in prey availability, disease, and contaminants (e.g. premature births accounted for 20-60% of pup mortality in the South Farallon Islands between 1973-83). Organochlorine and trace metal contaminant levels are still elevated in central California Steller sea lions (NMFS Biological Opinion 2000).

Steller sea lions feed on walleye pollock, capelin, mackerel, rockfish, herring, salmon, octopus and squid (see Riedman, 1990).

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

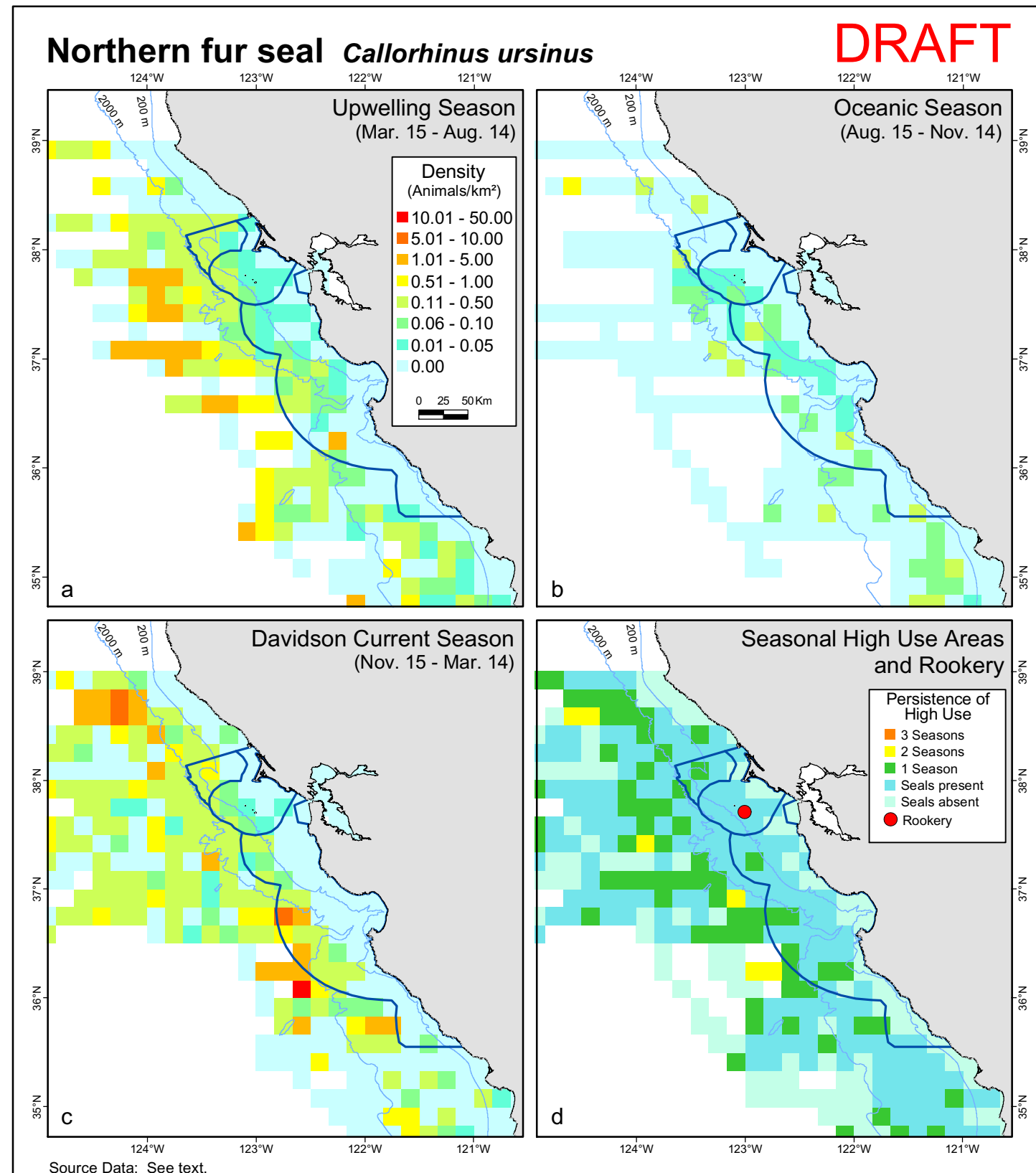


Figure 66. Maps for northern fur seal: seasonal at-sea densities, high use areas, and rookery.

ABOUT THESE MAPS

Figures 66a, b and c show the density (animals/km²) of northern fur seals in the Upwelling, Oceanic, and Davidson Current seasons, displayed in 10°x10' cells. Densities are based on combined data of several studies (see "Methods" and "Data Sources" sections). The color and mapping intervals were customized to show the most structure and highlight significant areas, while allowing comparisons among marine mammal species. Cells that were surveyed but which had no northern fur seal's have a density of zero; unsurveyed areas appear white. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200 m and 2,000 m isobaths are also shown in blue.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence in the study area, map d shows seasonal high use areas, displayed in 10'x10' cells. This map provides a further synthesis of densities presented in maps a, b and c (see "Methods" section for details), and portrays the relative importance of various areas to the species. Areas with consistent high use are highlighted on this map. To provide a relative reference for the "high use" areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there), or present but at lesser concentrations in any particular season. The single rookery location is also shown.

DATA SOURCES

At-sea densities for the northern fur seal are based on data from seven survey programs conducted in 1980-2001. These data were combined using CDAS software into the MMS-CDAS data system (MMS, 2001), developed for Minerals Management Service and expanded for this project. Of the data sets on the original CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program was still ongoing and data from recent years were added to this data set. In addition, data from three ship-based survey programs were converted to a compatible format for analysis. See "Data and Analyses" subsection in 2.3 for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (MMS, 2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDF&G-OSPR), unpublished data. Early data were collected using methods described by Bonnell et al. (1983); more recent data were collected using updated technology but with the same general method. Data sources for ship-based survey data include David Ainley, unpublished data (see Oedekoven et al. 2001 for details on methods). Although the at-sea data span the years 1980-2001, data are not available for all seasons in all years. For the

Upwelling Season, data are from 1980-1982 and 1985-2001. Oceanic Season, data are from 1980-1982, 1991, and 1994-2001. Davidson Current Season, data are from 1980-1986 and 1991-2001.

Information on the northern fur seal rookery was provided in 2003, courtesy of William Sydeman of PRBO Conservation Science, and Joelle Buffa of the Farallon Islands National Wildlife Refuge.

METHODS

At-sea densities are the result of a synthesis of data from seven shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources"). Pinniped observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into 10'x10' cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was censused more than once, densities were averaged, with adjustment made for effort.

Note that these maps represent either sighting locations or densities that used survey strip widths relative to each survey platform (e.g., plane, ship); density was calculated on the basis of the number of animals sighted and area surveyed. The data have only been corrected to normalize for survey effort and to exclude observations with winds greater than 25 knots (smaller or less obvious species are often less detectable even at wind speeds of less than 25 knots). Additional corrections are planned for Phase 2 of this project and are briefly discussed below.

For example, no adjustments or corrections have been made to account for differences in marine mammal detectability among species and differential probability of detecting animals from aerial and shipboard platforms. Individual body size, group size, and species-specific behaviors, such as proportion of time spent submerged, are all factors known to affect detection and hence, observed distribution and density estimates as well. Because of the very different attributes of aerial and shipboard platforms, these factors, and the associated adjustments for observations, vary among the studies.

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

Map d was developed using the same approach as for maps a, b and c. For each season, the cells with densities in the top 20% of non-zero values were designated “high use” for that season. Cells were scored for “high use” in one, two, or three seasons and are depicted by color. To provide a relative reference for the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season). Further detail on methods is provided in the "Data and Analysis" section.

RESULTS AND DISCUSSION

The northern fur seal, one of the most pelagic of the pinnipeds, is most abundant in continental shelf-slope waters of mid-latitudes off western North America during winter and early spring. Except for a small, recently re-established rookery (south Farallon Island, see below), rookeries occur primarily outside of the study area. The breeding and pupping season is June-July, and suckling can continue for three additional months. During autumn, adult females and juveniles migrate from rookeries on San Miguel Island in the southern California Bight (the San Miguel Island stock) and from the Eastern Pacific stock of the Pribilof Islands in the Bering Sea (Kajimura, 1980; Kenyon and Wilke, 1953; Pyle et al., 2001). Adult females and pups from the Pribilof Islands migrate into the North Pacific Ocean and to waters off Oregon and California.

In data used for this assessment (1980-2001), the northern fur seal was the second most abundant pinniped observed, with a total of 1,459 sightings and 2,070 individuals. In the study area, greatest densities occurred seaward of National Marine Sanctuary boundaries in the shelf-break, slope, and deep ocean habitats. The distinctly seasonal presence of this species is clearly evident in the study area, with greater numbers from February to May (Kajimura 1984). Greatest densities occur during the Upwelling and Davidson Current seasons (non-breeding period) and lesser densities during the Oceanic Season (breeding period).

Severe declines associated with periods of unusually warm ocean conditions affect pup production, mortality rates on San Miguel Island and the Pribilof Islands, and at-sea presence of this species (see DeLong and Antonelis, 1991; Allen, 1994; DeLong and Melin, 1999; Melin and DeLong, 2000; Keiper, 2001; and Keiper et al., *In Review*) In the early 19th century, American, British, and Russian sealers removed the breeding population from the South Farallon Islands (Pyle et al., 2001). Beginning in 1996, however, the species has re-established a breeding population on the South Farallon Islands, with fewer than 10 pups produced each year, 1997-2001 (Pyle et al., 2001). Seasonal high use areas occurred mostly to the west of National Marine Sanctuary boundaries.

Northern fur seals feed on a great diversity of seasonally abundant prey, and, off California, primary prey species include Pacific hake, northern anchovy, mesopelagic fishes, and market squid (Kajimura, 1984; see also Riedman, 1990).

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

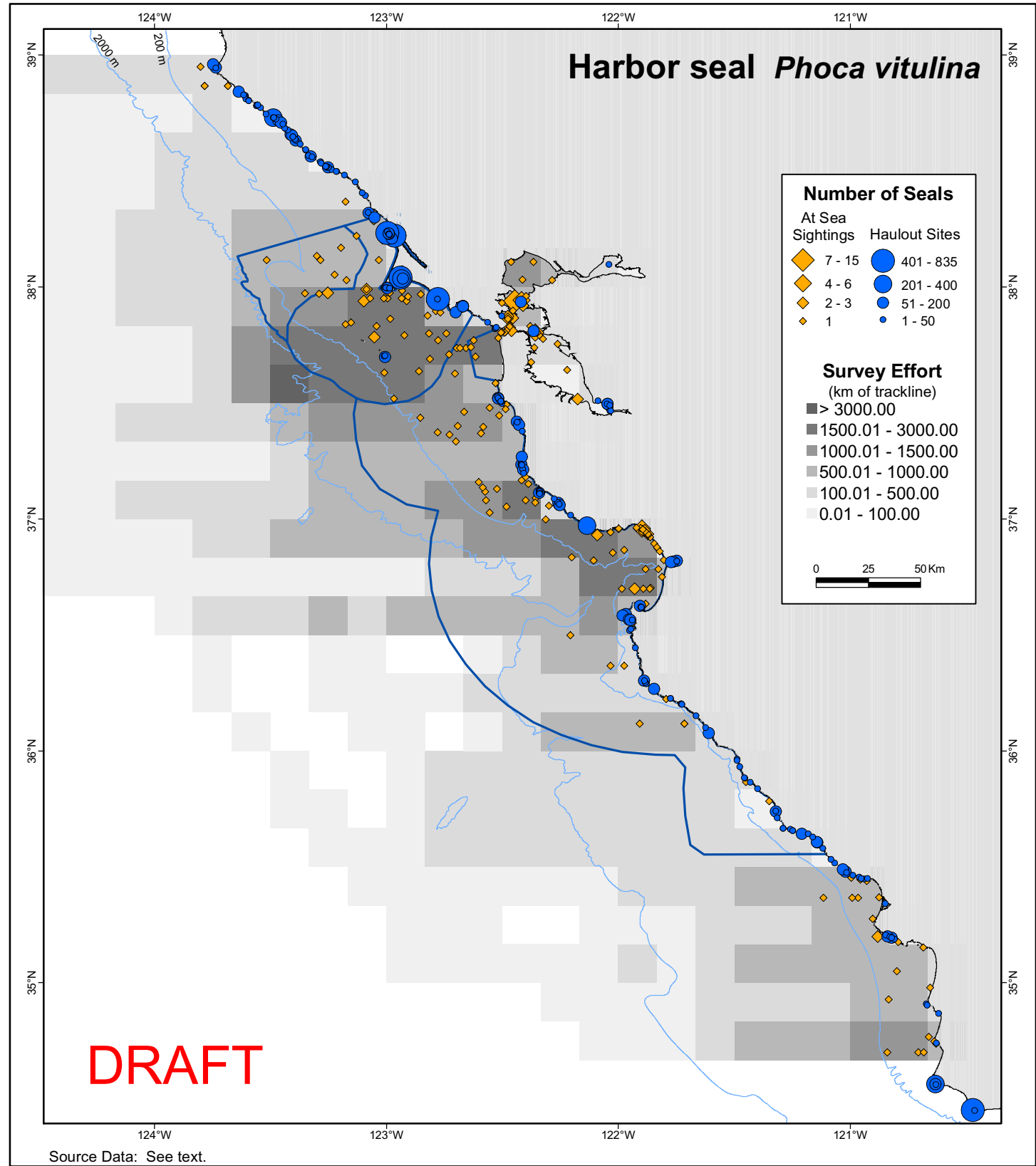


Figure 67. Map for harbor seal: at-sea sightings, survey effort and haulouts.

ABOUT THESE MAPS

Figure 67 shows individual sightings of harbor seals at sea along with the locations of haulouts and at-sea survey effort in the study area. At-sea observations are based on combined data of several studies (see "Methods" and "Data Sources" sections). For context, the amount of combined survey effort (km of trackline) is also shown, summarized in 10'x10' cells. Haulout locations are based on aerial counts from 2002. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200 m and 2,000 m isobaths are also shown in blue.

DATA SOURCES

At-sea sightings for the harbor seal are based on data from seven survey programs conducted in 1980-2001. These data were combined using CDAS software into the MMS-CDAS data system (MMS, 2001), developed for Minerals Management Service and expanded for this project. Of the data sets on the original CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program was still ongoing and data from recent years were added to this data set. In addition, data from three ship-based survey programs were converted to a compatible format for analysis. See "Data and Analyses" subsection of this mammal section (2.3).

Data sources for aerial at-sea data include MMS-CDAS (2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDFG-OSPR), unpublished data. Early data were collected using methods described by Bonnell et al. (1983); more recent data were collected using updated technology but with the same general method. Data sources for ship-based survey data include David Ainley, unpublished data (see Oedekoven et al., 2001 for details on methods). Although the overall at-sea data span the years 1980-2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991 and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001. Haulout information is from 2002 aerial survey data (6/12/2002-7/1/2002), from Mark Lowry of NMFS' Southwest Fisheries Science Center.

METHODS

The latitude/longitude coordinates of harbor seals at sea were used to plot the individual sightings. Haulouts were mapped coordinates provided by Mark Lowry. At-sea sightings and effort are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources"). Cetacean observation data and trackline data from these studies were converted to

a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, effort was mapped into 10'x10' cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS-CDAS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled.

Note that these maps represent either sighting locations or densities that used survey strip widths relative to each survey platform (e.g., plane, ship); density was calculated on the basis of the number of animals sighted and area surveyed. The data have only been corrected to normalize for survey effort and to exclude observations with winds greater than 25 knots; additional corrections are planned for Phase 2 of this project and are briefly discussed below.

For example, no adjustments/corrections have been made to account for differences in marine mammal detectability among species and differential probability of detecting animals from aerial and shipboard platforms. Individual body size, group size, and species-specific behaviors, such as proportion of time spent submerged, are all factors known to affect detection and hence, observed distribution and density estimates as well. Because of the very different attributes of aerial and shipboard platforms, these factors, and the associated adjustments for observations, vary among the studies.

The data in these maps include wind conditions of up to 25 knots; smaller or less obvious species are often less detectable even at wind speeds of less than 25 knots. The seasonal maps contain different combinations of shipboard and aerial data; therefore the seasonal densities from these platforms may not be directly comparable. A full consideration of these factors, and revised maps, are planned for Phase 2 of this project.

RESULTS AND DISCUSSION

The harbor seal is distributed from the eastern Aleutian Islands to Baja California and inhabits near-shore estuarine, coastal and shelf areas. When at sea, harbor seals were distributed in shelf habitats in relatively low densities in all three national marine sanctuaries; therefore, insufficient data precluded generating seasonal maps. Harbor seals forage throughout the coastal waters. Because the at-sea locations in this map are influenced by survey effort (where survey effort was unequal and coverage was less along the coast), the map may not accurately represent the foraging distribution of harbor seals. Although not evident in the maps, densities are higher in the Gulf of the Farallones because there are more and larger haul-out sites in this area (Allen et al., 2002). Harbor seals do

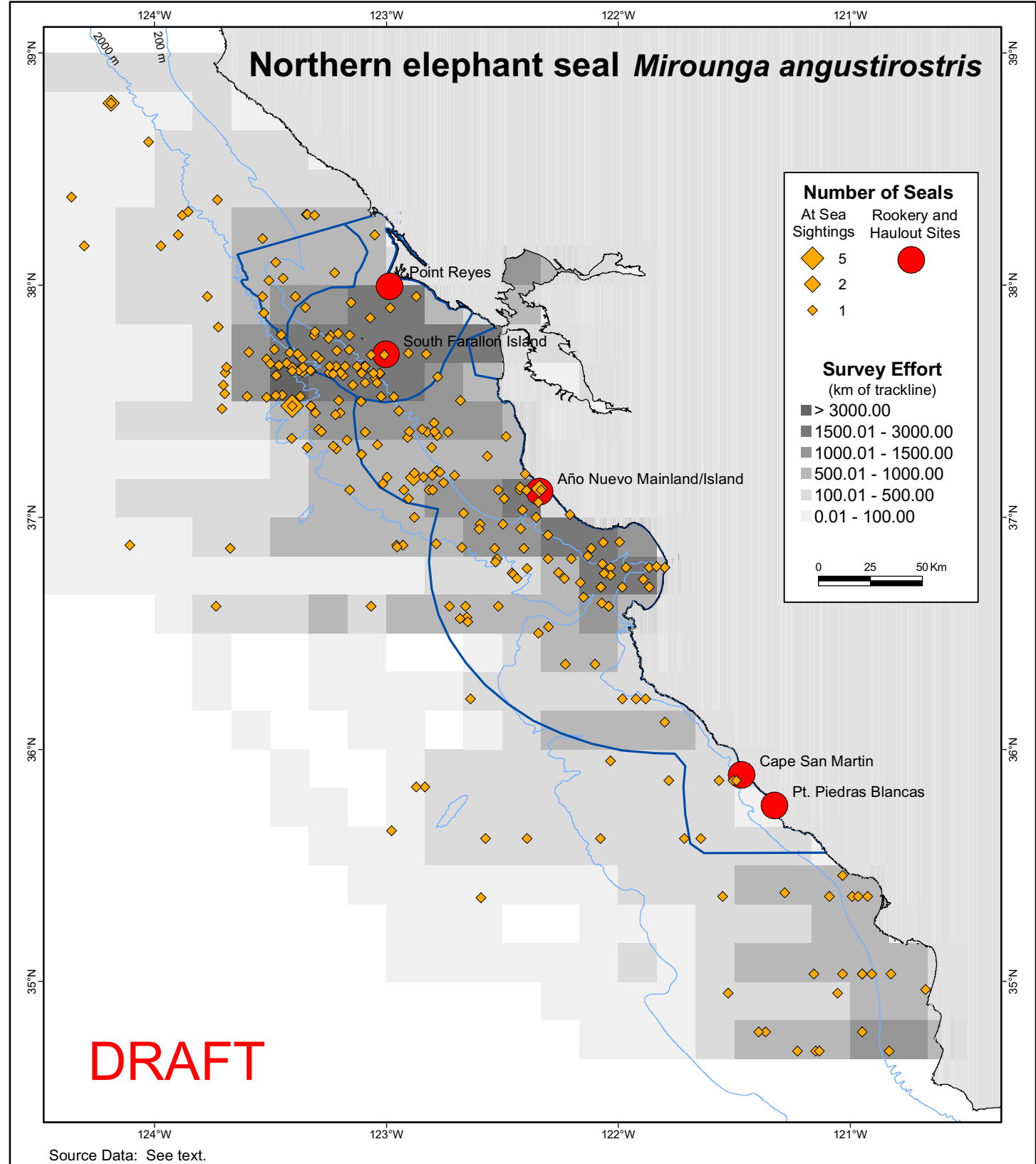
Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

not make extensive migrations, and tend to remain relatively close to their haul-out sites throughout the year. Harbor seals are inconspicuous at sea and may explain the relatively low numbers of animals surveyed at sea (sightings: n=192; individuals: n=235). A long-term monitoring project at Bolinas Lagoon (Gulf of the Farallones Sanctuary Education Awareness and Long-term Stewardship Program) protects the seals from human disturbance. During breeding and molting, relative abundance increases at Drakes Estero, whereas during winter (and during herring spawns) relative abundance increases in Tomales Bay. The Point Reyes region represents ~20% (6000 seals) of the breeding population of the state of California (S. Allen pers. comm.). Results of recent (2002) tagging studies have indicated individuals from San Francisco Bay travel to Duxbury Reef and out to the Farallon Islands to forage (S. Allen pers.comm.). Harbor seals feed on seasonally abundant prey that includes topsmelt, night smelt, white croaker, English sole (Harvey et al., 1995), salmonids (Weise, 2001), and squid and octopus (see also Riedman, 1990).

In the study area, the species is present year-round, and on land it is found on sandy beach, mudflat and rocky habitats. Haulout sites (identified by Lowry 2002) are located along the coast from Point Arena south to Point Conception, within San Francisco Bay, and at the Southeast Farallon Islands; habitat use at these sites, however, varies seasonally throughout the year (S. Allen, pers. comm.).

Breeding and pupping occurs March-July, and many pupping sites occur in the study area. Along the Point Reyes National Seashore, major pupping sites occur at the following locations (S. Allen pers.comm.): Bodega Rock, Bodega Point, Tomales Bay (four sites), Tomales Point (five sites), Drakes Estero (five sites), Limantour Spit, Double Point (two sites), Abalone Point, Bolinas Point, Duxbury Reef, Bolinas Lagoon (3 sites), Slide Ranch, and Point Bonita. Sites along the coast south of San Francisco may exist at Pescadero and Bean Hollow, but these sites are poorly documented (D.Greig, pers.comm.). Pupping sites within San Francisco Bay are located at Mowry Slough and Castro Rocks. Farther south, pupping sites also occur at Año Nuevo Island, Elkhorn Slough, Hopkins Marine Station, Cypress Point, Fanshell Beach and Cypress Point, San Lorenzo River and Point Lobos (D.Greig pers.comm.). A few pups (less than five) were also produced on South Farallon Island (USFWS, 2000).

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS



ABOUT THIS MAP

Figure 68 shows individual at-sea sightings of northern elephant seals at sea, along with the locations of rookeries and at-sea survey effort in the study area. At-sea observations are based on combined data of several studies (see “Methods” and “Data Sources” sections). For context, the amount of combined survey effort (km of trackline) is also shown, summarized in 10’x10’ cells. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200 m and 2,000 m isobaths are also shown in blue.

DATA SOURCES

At-sea sightings for the northern elephant seal are based on data from seven survey programs conducted in 1980-2001. These data were combined using CDAS software into the MMS-CDAS data system (MMS, 2001), developed for Minerals Management Service and expanded for this project. Of the data sets on the original CD-ROM, four aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program was still ongoing and data from recent years were added to this data set. In addition, data from three ship-based survey programs were converted to a compatible format for analysis; see Data and Analysis subsection for more information on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (MMS, 2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDFG-OSPR), unpublished data. Early data were collected using methods described by Bonnell et al. (1983); more recent data were collected using updated technology but with the same general method. Data sources for ship-based survey data include David Ainley, unpublished data (see Oedekoven et al., 2001 for details on methods). Although the at-sea data span the years 1980-2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991, and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001. Information on rookery locations was obtained from Pat Morris, USCS; Brian Hatfield, USGS; and Joelle Buffa, FWS.

METHODS

The latitude/longitude coordinates of northern elephant seals at sea were used to plot the individual sightings; the coordinates for rookeries and haulouts were used to plot their locations. At-sea sightings and effort are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see “Data Sources”). Cetacean observation data and trackline data from these studies were converted to a common format. All aerial data were

continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, effort was mapped into 10’x10’ cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled.

Note that these maps represent either sighting locations or densities that used survey strip widths relative to each survey platform (e.g., plane, ship); density was calculated on the basis of the number of animals sighted and area surveyed. The data have only been corrected to normalize for survey effort and to exclude observations with winds greater than 25 knots; additional corrections are planned for Phase 2 of this project and are briefly discussed below.

For example, no adjustments/corrections have been made to account for differences in marine mammal detectability among species and differential probability of detecting animals from aerial and shipboard platforms. Individual body size, group size, and species-specific behaviors, such as proportion of time spent submerged, are all factors known to affect detection and hence, observed distribution and density estimates as well. Because of the very different attributes of aerial and shipboard platforms, these factors, and the associated adjustments for observations, vary among the studies.

The data in these maps include wind conditions of up to 25 knots; smaller or less obvious species are often less detectable even at wind speeds of less than 25 knots. The seasonal maps contain different combinations of shipboard and aerial data; therefore the seasonal densities from these platforms may not be directly comparable. A full consideration of these factors, and revised maps, are planned for Phase 2 of this project.

RESULTS AND DISCUSSION

The northern elephant seal is present year-round in the study area; however, because they spend very little time at the surface, at-sea sightings are rare, as evidenced by the relatively few sightings during surveys in the study area (n=266 sightings; n=273 individuals). Therefore, insufficient data precluded mapping the northern elephant seal by seasons.

Northern elephant seals were widely distributed in shelf, shelf-break, and slope habitats within the three national marine sanctuaries, and also occurred in deep ocean habitats seaward of the 2000 m isobath. They also occurred well to the north, west, and south of sanctuary boundaries. In these data sets, age classes of at-sea sightings of seals are unknown.

Figure 68. Map for northern elephant seal: at-sea sightings and survey effort, rookeries and haulouts.

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

The northern elephant seal breeds, gives birth, and molts on islands and coastal regions in California, as well as offshore islands of Baja California. The breeding period in the study area is generally December through March (Stewart and Huber, 1993). Northern elephant seals migrate between rookeries located within sanctuary boundaries, Farallon Islands, Point Reyes, Año Nuevo Island and the mainland, Piedras Blancas, Cape San Martin, and San Simeon, and waters to the north, where they spend eight to ten months of the year feeding. Adult males feed in the eastern Aleutian Islands and the Gulf of Alaska; adult females feed to the west and south of 45° N in deep, oceanic water (Le Boeuf et al., 1993; Stewart and Huber, 1993; Stewart et al., 1994).

On land, there are three peaks in abundance: 1) during the breeding/pupping season December to March, with peaks the last week of January; 2) during the molting season when female and immatures are on shore April to July with peaks in May, and adult males are on shore June to early August; and 3) during September to October when immatures haul-out (S. Allen, pers. comm). Pups depart the pupping sites during the Upwelling Season. Recent tagging studies indicate that pups from this region travel as far as Alaska (S.Allen, unpublished data, National Park Service).

Each year at Año Nuevo Island and mainland, there are approximately 2,400 females and 300-400 males present, and approximately 2,200 pups are produced (P. Morris, pers. comm, 2003). Based on pup counts, the population there steadily increased through the mid 1990s, but now appears to be stable (P. Morris, pers. comm., credited to B.J. Le Boeuf). In contrast, the colony at Piedras Blancas has continued to rise (in general) over the past five years (B. Hatfield, pers. comm.) Productivity has declined at two major breeding sites on Southeast Farallon Island (Sydeman and Allen, 1999; Nusbaum, 2002), with erosion playing a major role in limiting the species' population (USFWS 2000). In California, the net productivity rate for northern elephant seals also appears to have declined in recent years (Carretta et al., 2002). However, the colony at Point Reyes Headlands has continued to increase by 5-10% per year (Sydeman and Allen, 1999; S. Allen, pers. comm. 2003). Due to the high surf during the strong El Niño of 1998, extensive pup mortality occurred at the Point Reyes colony (Petree, 1999), but also forced the relocation of the breeding area; some moved from the main colony at Point Reyes Headlands to South Beach and North Drakes Bay Beach (Petree, 1999).

Northern elephant seals are prolonged deep divers that feed on deepwater fishes and invertebrates, including Pacific hagfish (*Eptatretus stouti*), rattfish (*Hydrolagus colliei*), Pacific hake, rockfish, sharks, rays, squid and octopus (Antonelis et al., 1987; Condit and LeBoeuf, 1984).

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

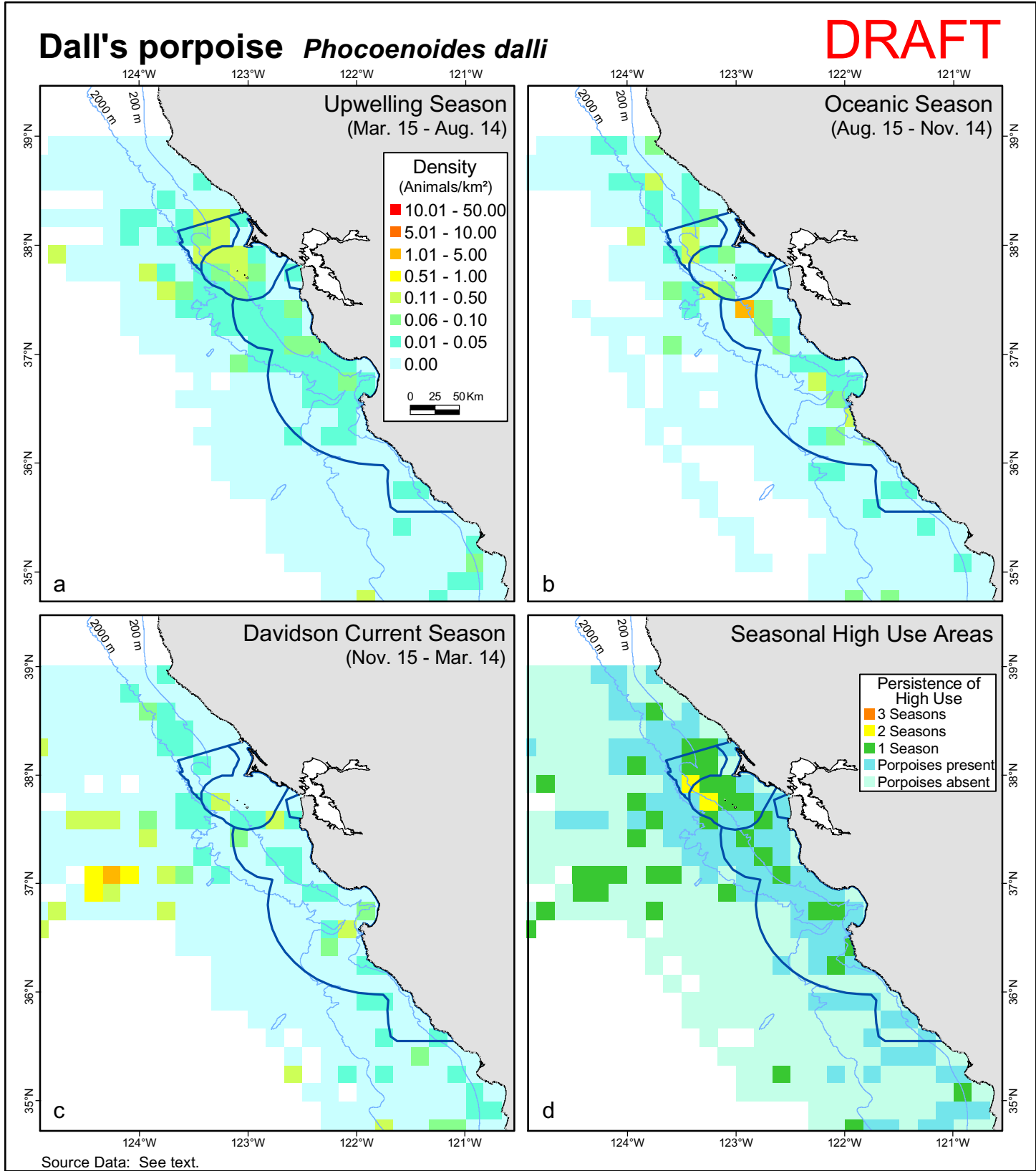


Figure 69. Maps for Dall's porpoise: seasonal at-sea densities and high use areas.

ABOUT THESE MAPS

Figures 69a, b and c show the density (animals/km²) of Dall's porpoise in the Upwelling, Oceanic, and Davidson Current seasons, displayed in 10'x10' cells. Densities are based on combined data of several studies (see "Methods" and "Data Sources" sections). The color and mapping intervals were customized to highlight significant areas and the structure of species spatial occurrence, while allowing comparisons among marine mammal species. Cells that were surveyed but which had no Dall's porpoise have a density of zero; unsurveyed areas appear white. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200 m and 2,000 m isobaths are also shown in blue.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence year-round in the study area, map d shows seasonal high use areas, displayed in 10'x10' cells. This map provides a further synthesis of densities presented in maps a, b and c (see the "Methods" section for details), and portrays the relative importance of various areas to the species. Areas of consistent high use (colored according to the number of high seasonal use) are highlighted on this map. To provide a relative reference for the "high use" areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there) or present but at lower concentrations (densities in a cell were never in the top 20%) in any particular season.

DATA SOURCES

At-sea densities for cetaceans are based on data from eight survey programs conducted in 1980-2001. These data were combined using CDAS software into the MMS-CDAS data system (MMS, 2001), developed for Minerals Management Service and expanded for this project. Of the data sets on the original CD-ROM, five aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program was still ongoing and data from recent years were added to this data set. In addition, data from three ship-based survey programs were converted to a compatible format for analysis. See "Data and Analyses" subsection in 2.3 for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (MMS, 2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDF&G-OSPR), unpublished data. Early data were collected using methods described by Bonnell et al. (1983) and Dohl et al. (1983); more recent data were collected using updated technology but with the same general method. Data sources for ship-based survey data include David Ainley, unpublished data (see Oedekoven et al. 2001 for details on methods). Although the at-sea data span

the years 1980-2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991, and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard or aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources"). Cetacean observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into 10'x10' cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of cetaceans of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was censused more than once, densities were averaged, with adjustment made for effort.

Note that these maps represent either sighting locations or densities that used survey strip widths relative to each survey platform (e.g., plane, ship); density was calculated on the basis of the number of animals sighted and area surveyed. The data have only been corrected to normalize for survey effort and to exclude observations with winds greater than 25 knots (smaller or less obvious species are often less detectable even at wind speeds of less than 25 knots). Additional corrections are planned for Phase 2 of this project and are briefly discussed below.

For example, no adjustments or corrections have been made to account for differences in marine mammal detectability among species and differential probability of detecting animals from aerial and shipboard platforms. Individual body size, group size, and species-specific behaviors, such as proportion of time spent submerged, are all factors known to affect detection and hence, observed distribution and density estimates as well. Because of the very different attributes of aerial and shipboard platforms, these factors, and the associated adjustments for observations, vary among the studies.

Map d was developed using the same approach as for maps a, b and c. For each season, the cells with densities in the top 20% of non-zero values were designated "high use" for that season. Cells were scored for "high use" in one, two, or three seasons and are depicted by color. To provide a relative reference for

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season). Further detail on methods is provided in the "Data and Analysis" section.

RESULTS AND DISCUSSION

Dall’s porpoise is widely distributed in temperate North Pacific waters. In the study area, this species was the fourth most numerous small cetacean. Dall’s porpoise was present during all seasons in shelf, upper/lower slope, canyon, and deep ocean habitats seaward of the 2000 m isobath.

During the Upwelling Season densities were somewhat greater in the Cordell Bank National Marine Sanctuary (NMS) and northern regions of the Gulf of the Farallones NMS. During the Oceanic Season, densities were somewhat greater within and to the north of Cordell Bank and the northern portion of the Monterey Bay National Marine Sanctuary (MBNMS). The widespread and deep ocean distribution of the Dall’s porpoise (well to the west of the National Marine Sanctuary boundaries) was most evident during the Davidson Current Season (when effort was greater offshore). No clear seasonal pattern was evident.

The distribution of Dall’s porpoise is highly variable between years and appears to be affected by oceanographic conditions (Forney and Barlow 1998). North-south movements of this species occur as oceanographic conditions change on seasonal and interannual time scales (see Green et al., 1992; Barlow, 1995; Forney et al., 1995).

High use areas (based on the CDAS maps) occurred along the 200 m isobath in the Cordell Bank and Gulf of the Farallones NMS. Given the highly variable distribution of Dall’s porpoise, the apparent higher relative density in these regions may not be a seasonal pattern.

See map of SWFSC survey data for Dall’s porpoise (Figure 76) in this section for the greater geographic extent of the range and interannual variations for this species.

Dall’s porpoise feeds mostly on Pacific hake (*Merluccius productus*), northern anchovy (*Engraulis mordax*), Pacific saury (*Cololabis saira*), juvenile rockfish (*Sebastes* spp), and cephalopods (Koskii et al., 1998; Morejohn, 1979).

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

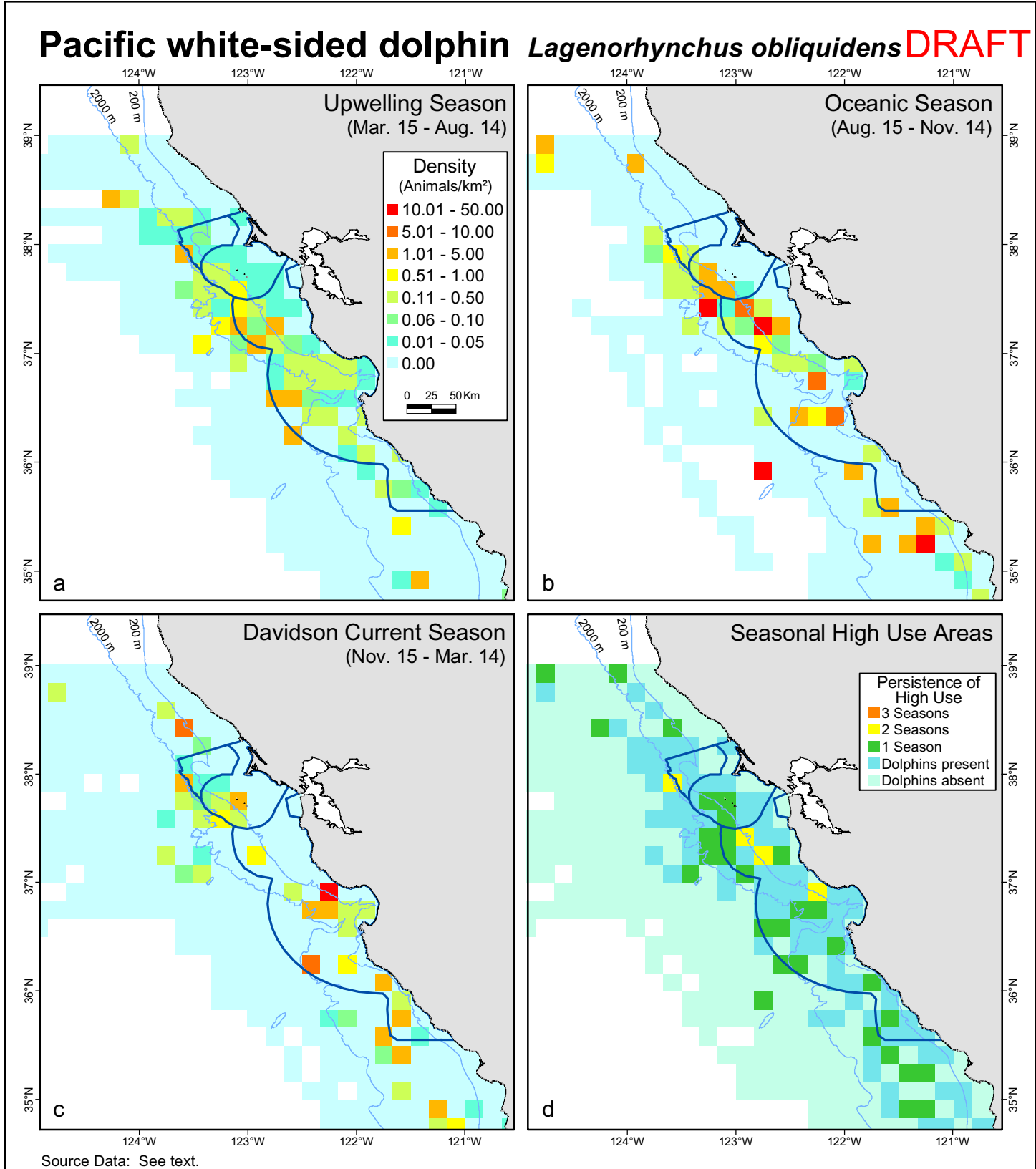


Figure 70. Maps for Pacific white-sided dolphin: seasonal at-sea densities and high use areas.

ABOUT THESE MAPS

Figures 70a, b and c show the density (animals/km²) of Pacific white-sided dolphin in the Upwelling, Oceanic, and Davidson Current seasons, displayed in 10'x10' cells. Densities are based on combined data of several studies (see "Methods" and "Data Sources" sections). The color and mapping intervals were customized to show the most structure and highlight significant areas, while allowing comparisons among marine mammal species. Cells that were surveyed but which had no Pacific white-sided dolphins have a density of zero; unsurveyed areas appear white. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200m and 2,000m isobaths are also shown in blue.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence in the study area, map d shows seasonal high use areas, displayed in 10'x10' cells. This map provides a further synthesis of densities presented in maps a, b and c (see the "Methods" section for details), and portrays the relative importance of various areas to the species. Areas with consistent high use are highlighted on this map. To provide a relative reference for the "high use" areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there), or present but at lesser concentrations in any particular season.

DATA SOURCES

At-sea densities for cetaceans are based on data from eight survey programs conducted in 1980-2001. These data were combined using CDAS software into the MMS-CDAS data system (MMS, 2001), developed for Minerals Management Service and expanded for this project. Of the data sets on the original CD-ROM, five aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program was still ongoing and data from recent years were added to this data set. In addition, data from three ship-based survey programs were converted to a compatible format for analysis. See "Data and Analyses" subsection in 2.3 for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (MMS, 2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDF&G-OSPR), unpublished data. Early data were collected using methods described by Bonnell et al. (1983) and Dohl et al. (1983); more recent data were collected using updated technology but with the same general method. Data sources for ship-based survey data include David Ainley, unpublished data (see Oedekoven et al., 2001 for details on methods). Although the at-sea data span the years 1980-2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982

and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991 and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources" section). Cetacean observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into 10'x10' cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of cetaceans of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was censused more than once, densities were averaged, with adjustment made for effort.

Note that these maps represent either sighting locations or densities that used survey strip widths relative to each survey platform (e.g., plane, ship); density was calculated on the basis of the number of animals sighted and area surveyed. The data have only been corrected to normalize for survey effort and to exclude observations with winds greater than 25 knots (smaller or less obvious species are often less detectable even at wind speeds of less than 25 knots). Additional corrections are planned for Phase 2 of this project and are briefly discussed below.

For example, no adjustments or corrections have been made to account for differences in marine mammal detectability among species and differential probability of detecting animals from aerial and shipboard platforms. Individual body size, group size, and species-specific behaviors, such as proportion of time spent submerged, are all factors known to affect detection and hence, observed distribution and density estimates as well. Because of the very different attributes of aerial and shipboard platforms, these factors, and the associated adjustments for observations, vary among the studies.

Map d was developed using the same approach as for Maps a, b and c. For each season, the cells with densities in the top 20% of non-zero values were designated "high use" for that season. Cells were scored for "high use" in one, two, or three seasons and are depicted by color. To provide a relative reference for the "high use" areas, cells are also shown where the species

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season). Further detail on methods is provided in the "Data and Analysis" section.

RESULTS AND DISCUSSION

The Pacific white-sided dolphin is one of the most abundant dolphin species of the temperate eastern North Pacific. In the present study, it was the most abundant of the small cetaceans (sightings: $n=456$; numbers of individuals: $n=28,809$). Pacific white-sided dolphins occurred throughout the study area during all oceanographic seasons in outer shelf, upper/lower slope and canyon habitats.

Some seasonal shifts in the occurrence of Pacific white-sided dolphins were observed in the data; densities were relatively greater during the Oceanic Season, with concentrations near Pioneer Canyon and Pioneer Seamount and regions over Monterey Canyon. Because the occurrence of Pacific white-sided dolphins is highly variable and this species responds to oceanographic conditions on both seasonal and interannual time scales (see Forney and Barlow, 1998), the apparent seasonal shifts observed in these data may not be a seasonal pattern.

However, in a study in Monterey Bay (Black, 1994), group size and relative abundance of the Pacific white-sided dolphin varied seasonally and was greater during the Oceanic and Davidson Current Seasons than during the Upwelling Season, when relative individual and group abundance was low and group sizes were small (not shown in maps; Black, 1994).

Furthermore, in habitats over and near shelf-breaks and greater bottom relief, feeding behavior was observed more than other behaviors (Black, 1994). Based on available information, high use areas mostly occurred over the slope.

Prey of the Pacific white-sided dolphin includes: Pacific whiting, northern anchovy, rockfish, Pacific saury, and market squid (*Loligo opalescens*) (Stroud et al., 1981; Black, 1994).

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

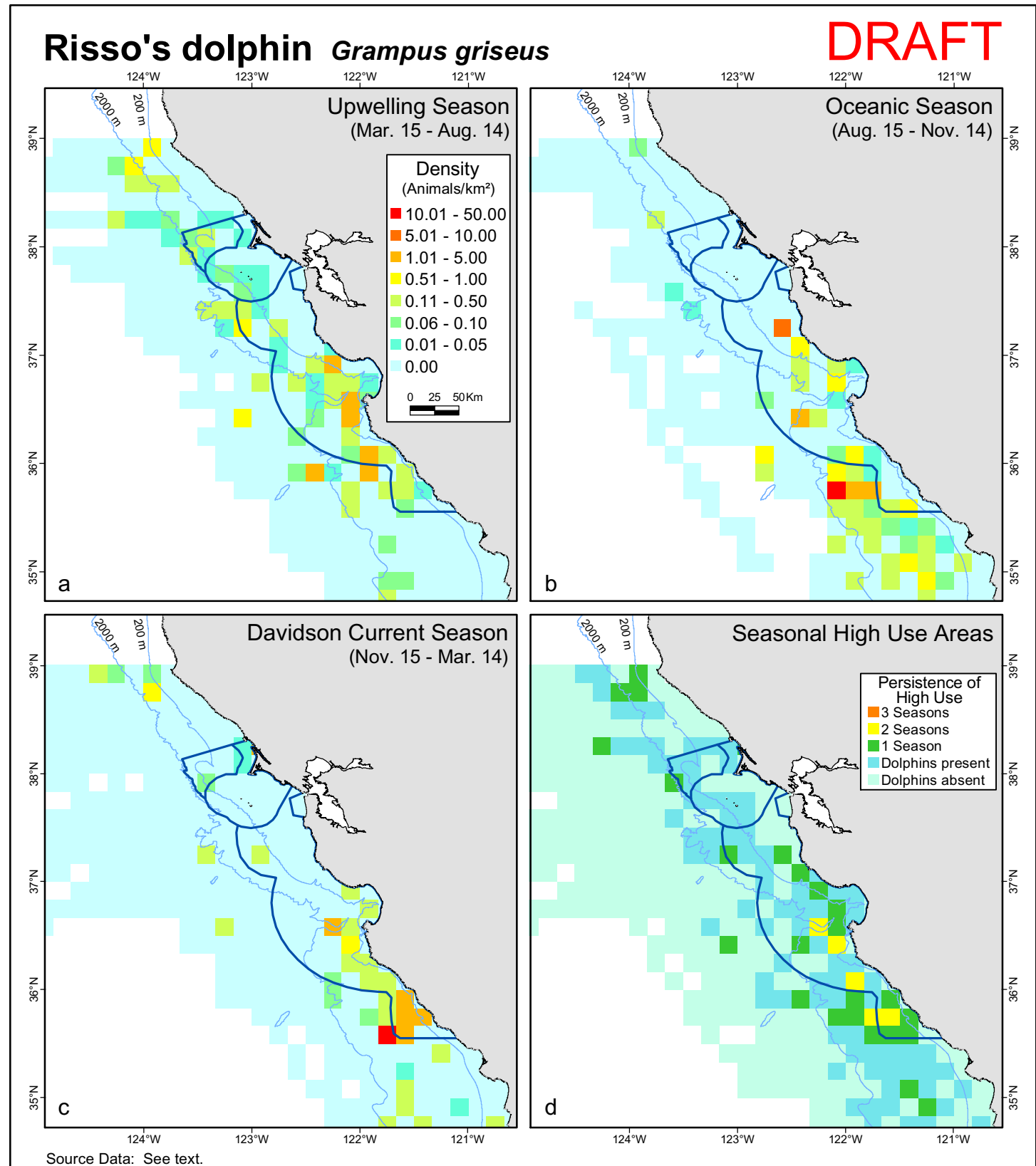


Figure 71. Maps for Risso's dolphin: seasonal at-sea densities and high use areas.

ABOUT THESE MAPS

Figures 71a, b and c show the density (animals/km²) of Risso's dolphin in the Upwelling, Oceanic, and Davidson Current seasons, displayed in 10'x10' cells. Densities are based on combined data of several studies (see "Methods" and "Data Sources" sections). The color and mapping intervals were customized to show the most structure and highlight significant areas, while allowing comparisons among marine mammal species. Cells that were surveyed but which had no Risso's dolphins have a density of zero; unsurveyed areas appear white. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200m and 2,000m isobaths are also shown in blue.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence in the study area, map d shows seasonal high use areas, displayed in 10'x10' cells. This map provides a further synthesis of densities presented in maps a, b and c (see "Methods" section for details), and portrays the relative importance of various areas to the species. Areas with consistent high use are highlighted on this map. To provide a relative reference for the "high use" areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there) or present but at lesser concentrations in any particular season.

DATA SOURCES

At-sea densities for cetaceans are based on data from eight survey programs conducted in 1980-2001. These data were combined using CDAS software into the MMS-CDAS data system (MMS, 2001), developed for Minerals Management Service and expanded for this project. Of the data sets on the original CD-ROM, five aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program was still ongoing and data from recent years were added to this data set. In addition, data from three ship-based survey programs were converted to a compatible format for analysis. See "Data and Analyses" subsection in 2.3 for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (MMS, 2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDF&G-OSPR), unpublished data. Early data were collected using methods described by Bonnell et al. (1983) and Dohl et al. (1983); more recent data were collected using updated technology but with the same general method. Data sources for ship-based survey data include David Ainley, unpublished data (see Oedekoven et al. 2001 for details on methods). Although the at-sea data span the years 1980-2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982

and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991 and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources" section). Cetacean observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into 10'x10' cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of cetaceans of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was censused more than once, densities were averaged, with adjustment made for effort.

Note that these maps represent either sighting locations or densities that used survey strip widths relative to each survey platform (e.g., plane, ship); density was calculated on the basis of the number of animals sighted and area surveyed. The data have only been corrected to normalize for survey effort and to exclude observations with winds greater than 25 knots (smaller or less obvious species are often less detectable even at wind speeds of less than 25 knots). Additional corrections are planned for Phase 2 of this project and are briefly discussed below.

For example, no adjustments or corrections have been made to account for differences in marine mammal detectability among species and differential probability of detecting animals from aerial and shipboard platforms. Individual body size, group size, and species-specific behaviors, such as proportion of time spent submerged, are all factors known to affect detection and hence, observed distribution and density estimates as well. Because of the very different attributes of aerial and shipboard platforms, these factors, and the associated adjustments for observations, vary among the studies.

Map d was developed using the same approach as for maps a, b and c. For each season, the cells with densities in the top 20% of non-zero values were designated "high use" for that season. Cells were scored for "high use" in one, two, or three seasons and are depicted by color. To provide a relative reference for the "high use" areas, cells are also shown where the species

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season). Further detail on methods is provided in the "Data and Analysis" section.

RESULTS AND DISCUSSION

The Risso's dolphin is widely distributed in warm-temperate waters from southern California north to Washington, and in the study area, occurred over outer shelf, upper and lower slope, and canyon habitats, and in offshore waters seaward of the 2000 m isobath. Risso's dolphin was the third most abundant dolphin in the study area, with 250 sightings of 2,248 individuals.

During the Upwelling Season, Risso's dolphins were distributed throughout the study area over the outer shelf, slope and deep ocean, with greatest densities in (and to the south and west of) the Monterey Bay National Marine Sanctuary (MBNMS). During the Oceanic Season, greatest densities occurred within and south and west of the southern portion of MBNMS. During the Davidson Current Season, overall densities were mostly in the southern portion of the MBNMS and areas to the south and west of the MBNMS boundary.

Distribution of Risso's dolphin off California, Oregon, and Washington is highly variable, apparently in response to seasonal and interannual oceanographic changes (Forney and Barlow, 1998). Dolphins found off California during colder water months are thought to shift northward into Oregon and Washington as water temperatures increase in late spring and summer (Carretta et al., 2001; Green et al., 1992). Given the highly variable distribution of Risso's dolphin, the apparent relative decrease in relative density observed in this study during the Davidson Current Season may not be a seasonal pattern. Based on this data set, most high use areas occurred in the Monterey Bay national marine sanctuary and adjacent areas to the south (see map).

Risso's dolphin feed almost exclusively on squid (Koski et al., 1998; Orr, 1966).

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

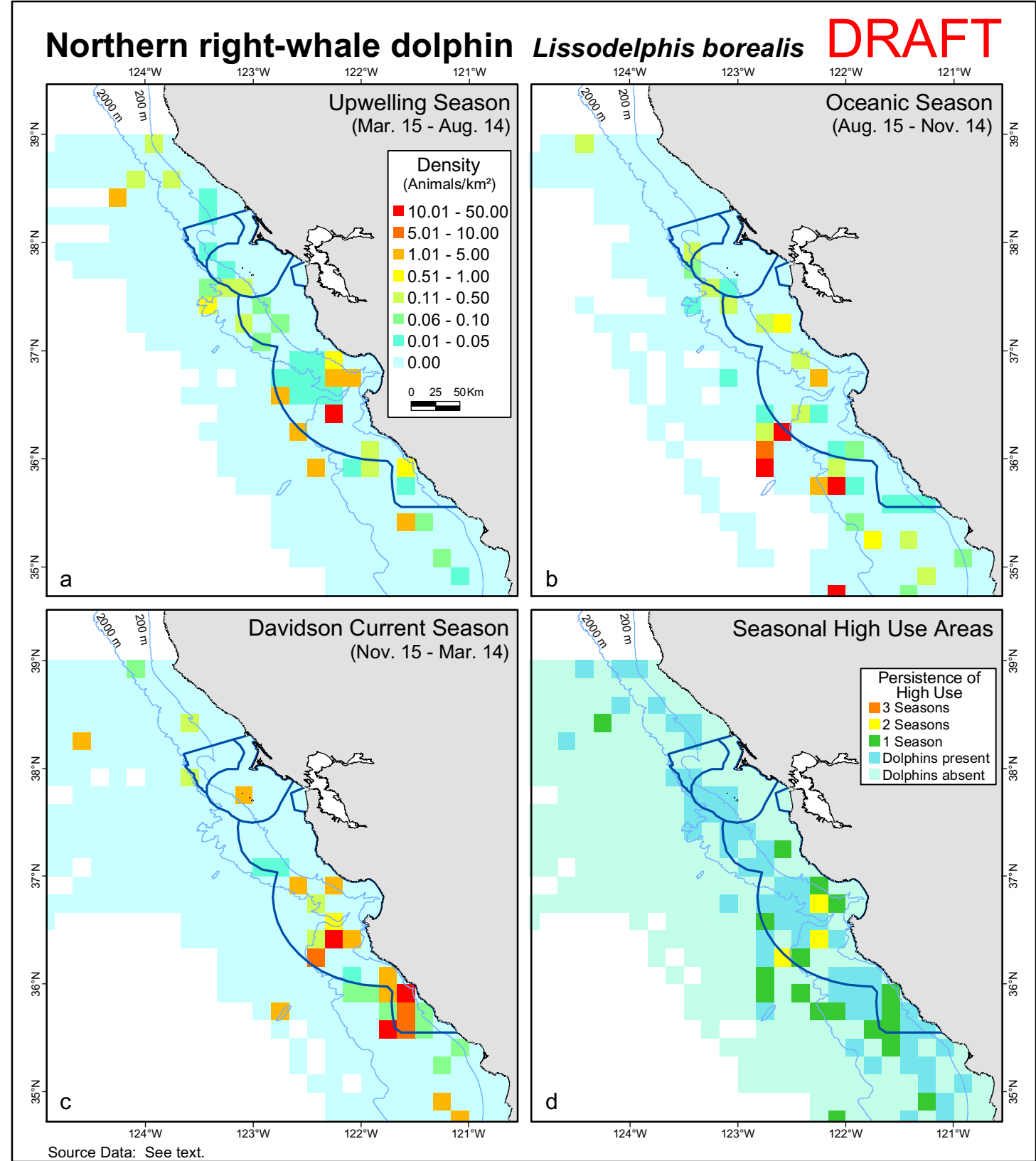


Figure 72. Maps for northern right-whale dolphin: seasonal at-sea densities and high use areas.

ABOUT THESE MAPS

Figures 72a, b and c show the density (animals/km²) of northern right whale dolphins in the Upwelling, Oceanic, and Davidson Current seasons, displayed in 10'x10' cells. Densities are based on combined data of several studies (see "Methods" and "Data Sources"). The color and mapping intervals were customized to show the most structure and highlight significant areas, while allowing comparisons among marine mammal species. Cells that were surveyed but which had no northern right whale dolphins have a density of zero; unsurveyed areas appear white. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200m and 2,000m isobaths are also shown in blue.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence in the study area, map d shows seasonal high use areas, displayed in 10'x10' cells. This map provides a further synthesis of densities presented in maps a, b and c (see "Methods" section for details), and portrays the relative importance of various areas to the species. Areas with consistent high use are highlighted on this map. To provide a relative reference for the "high use" areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there), or present but at lesser concentrations in any particular season.

DATA SOURCES

At-sea densities for cetaceans are based on data from eight survey programs conducted in 1980-2001. These data were combined using CDAS software into the MMS-CDAS data system (MMS, 2001), developed for Minerals Management Service and expanded for this project. Of the data sets on the original CD-ROM, five aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program was still ongoing and data from recent years were added to this data set. In addition, data from three ship-based survey programs were converted to a compatible format for analysis. See section introduction for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (MMS, 2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDF&G-OSPR), unpublished data. Early data were collected using methods described by Bonnell et al. (1983) and Dohl et al. (1983); more recent data were collected using updated technology but with the same general method. Data sources for ship-based survey data include David Ainley, unpublished data (see Oedekoven et al., 2001 for details on methods). Although the at-sea data span the years 1980-2001, data are not available for all seasons in all years. Upwelling Season, data are from 1980-1982 and

1985-2001. Oceanic Season, data are from 1980-1982, 1991 and 1994-2001. Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources" section). Cetacean observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into 10'x10' cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of cetaceans of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was censused more than once, densities were averaged, with adjustment made for effort.

Note that these maps represent either sighting locations or densities that used survey strip widths relative to each survey platform (e.g., plane, ship); density was calculated on the basis of the number of animals sighted and area surveyed. The data have only been corrected to normalize for survey effort and to exclude observations with winds greater than 25 knots (smaller or less obvious species are often less detectable even at wind speeds of less than 25 knots). Additional corrections are planned for Phase 2 of this project and are briefly discussed below.

For example, no adjustments or corrections have been made to account for differences in marine mammal detectability among species and differential probability of detecting animals from aerial and shipboard platforms. Individual body size, group size, and species-specific behaviors, such as proportion of time spent submerged, are all factors known to affect detection and hence, observed distribution and density estimates as well. Because of the very different attributes of aerial and shipboard platforms, these factors, and the associated adjustments for observations, vary among the studies.

Map d was developed using the same approach as for maps a, b and c. For each season, the cells with densities in the top 20% of non-zero values were designated "high use" for that season. Cells were scored for "high use" in one, two, or three seasons and are depicted by color. To provide a relative reference for the "high use" areas, cells are also shown where the species

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season). Further detail on methods is provided in the "Data and Analysis" section.

RESULTS AND DISCUSSION

The northern right whale dolphin occurs in the temperate North Pacific, primarily in shelf, slope, and to some degree, deep ocean waters. In the study area, this species occurred in outer shelf, slope and canyon habitats. The northern right whale dolphin was the second most abundant small cetacean in the study area, with 135 sightings of 22,578 individuals.

Distribution of northern right whale dolphins is highly variable, apparently in response to seasonal and interannual oceanographic changes (Forney and Barlow, 1998). Northern right whale dolphins are found primarily off California during colder-water months and shift northward into Oregon and Washington as water temperatures increase in late spring and summer (Carretta et al., 2001; Forney and Barlow, 1998). Patterns of seasonal abundance have been observed throughout their range, but there is no information to indicate that large numbers move between California, Oregon, and Washington waters (Green et al., 1992). In this study, the apparent increase in relative densities in the southern portion of MBNMS during the Davidson Current Season may not be a seasonal pattern, given the highly variable distribution of northern right whale dolphins, apparently in response to seasonal and interannual oceanographic changes (Forney and Barlow, 1998).

Northern right whale dolphins feed on mesopelagic fishes (e.g. lanternfish) and squid (Leatherwood and Reeves, 1983).

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

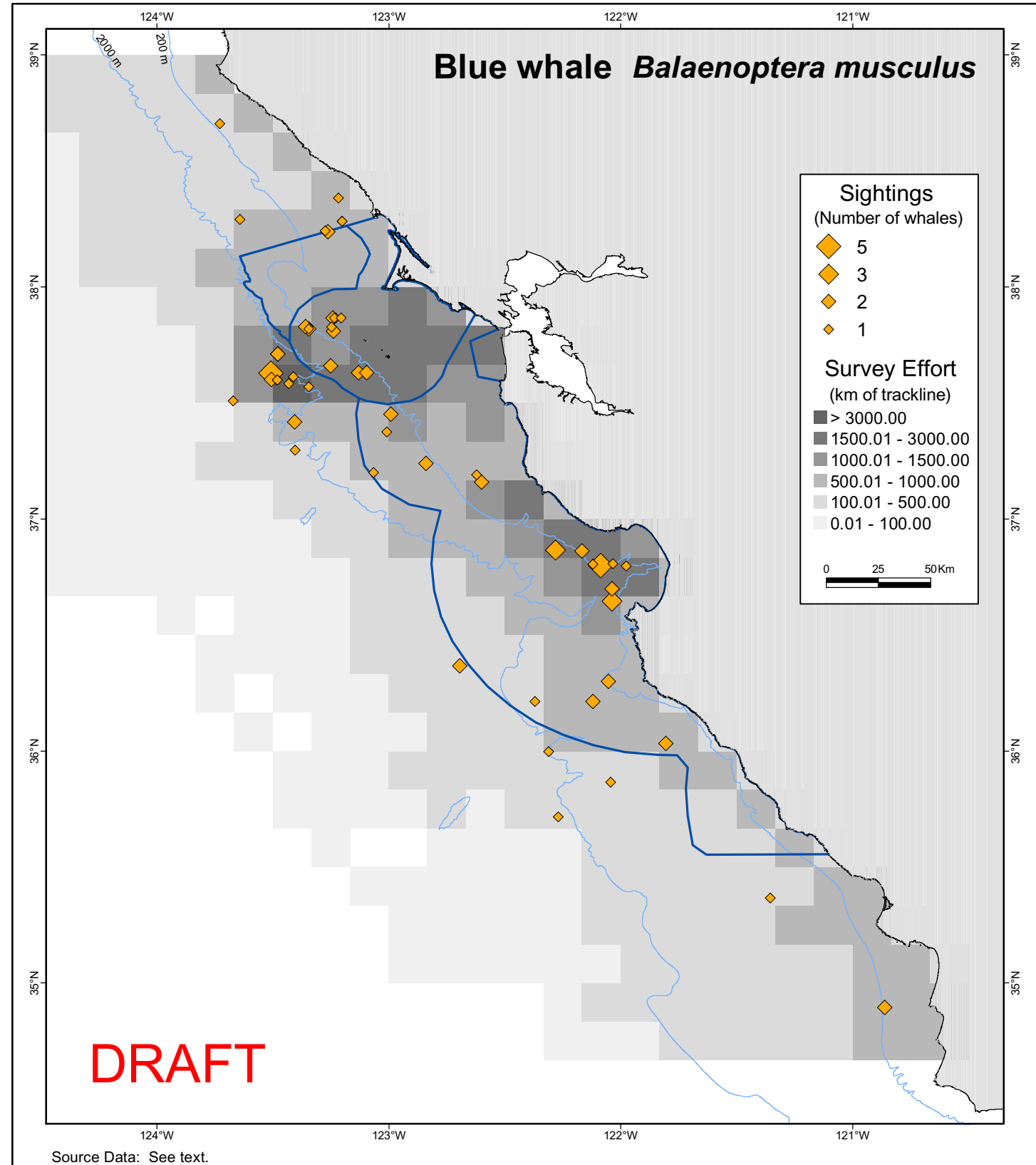


Figure 73. Map for blue whale: at-sea sightings and survey effort.

ABOUT THIS MAP

Figure 73 shows the individual sightings of blue whales at sea, along with at-sea survey effort. Due to insufficient sightings in the data set (49 sightings of 77 individuals) for the study area, seasonal maps of blue whale density were not generated. At-sea sightings for cetaceans are from several studies (see "Methods" and "Data Sources" sections). For context, the combined survey effort is also shown, summarized in 10'x10' cells. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200m and 2,000m isobaths are also shown in blue. Additional data to be added in Phase II may make it possible to develop seasonal maps.

DATA SOURCES

At-sea sightings for cetaceans are based on data from eight survey programs conducted in 1980-2001. These data were combined using CDAS software into the MMS-CDAS data system (MMS, 2001), developed for Minerals Management Service and expanded for this project. Of the data sets on the original CD-ROM, five aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program was still ongoing and data from recent years were added to this data set. In addition, data from three ship-based survey programs were converted to a compatible format for analysis. See section introduction for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (MMS, 2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDFG-OSPR), unpublished data. Early data were collected using methods described by Bonnell et al. (1983) and Dohl et al. (1983); more recent data were collected using updated technology but with the same general method. Data sources for ship-based survey data include David Ainley, unpublished data (see Oedekoven et al., 2001 for details on methods). Although the at-sea data span the years 1980-2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991 and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

The latitude and longitude coordinates for blue whales at sea were used to plot the individual sightings. At-sea sightings and effort are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources"). Cetacean observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to

the extent possible. From the digitized survey data, effort was mapped into 10'x10' cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled.

Note that the these maps represent either sighting locations or densities that used survey strip widths relative to each survey platform (e.g., plane, ship); density was calculated on the basis of the number of animals sighted and area surveyed. The data have only been corrected to normalize for survey effort and to exclude observations with winds greater than 25 knots; additional corrections are planned for Phase 2 of this project and are briefly discussed below.

For example, no adjustments/corrections have been made to account for differences in marine mammal detectability among species and differential probability of detecting animals from aerial and shipboard platforms. Individual body size, group size, and species-specific behaviors, such as proportion of time spent submerged, are all factors known to affect detection and hence, observed distribution and density estimates as well. Because of the very different attributes of aerial and shipboard platforms, these factors, and the associated adjustments for observations, vary among the studies.

The data in these maps include wind conditions of up to 25 knots; smaller or less obvious species are often less detectable even at wind speeds of less than 25 knots. The seasonal maps contain different combinations of shipboard and aerial data; therefore the seasonal densities from these platforms may not be directly comparable. A full consideration of these factors, and revised maps, are planned for Phase 2 of this project.

RESULTS AND DISCUSSION

The blue whale is federally listed as endangered under the Endangered Species Act. One population of blue whale (there may be as many as five (Carretta et al., 2001; Reeves et al., 1998)) is present in California waters, generally from June through November. Arrival and departure times in the study area are highly variable both seasonally and inter-annually (see Benson et al., 2002; Calambokidis et al., 1998).

Movement patterns, distribution, and occurrence of blue whales off California are related to their annual migration between foraging areas predominately off central California (but some north to British Columbia and south to Baja Mexico and the Costa Rican Dome), and the following breeding areas: 1) off the west coast of Baja California (September-December), 2) the Gulf of California (January-April), and 3) the Costa Rica

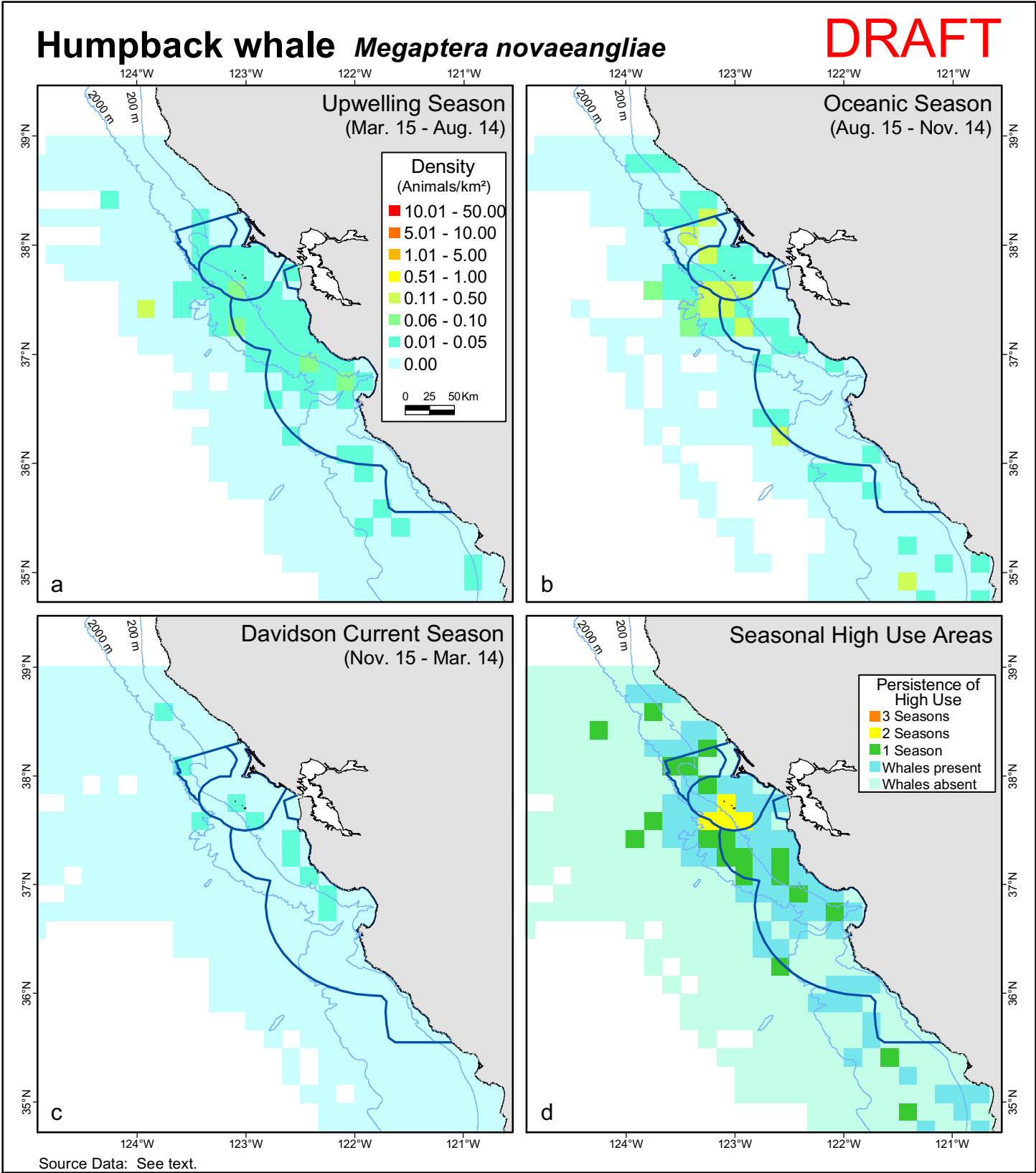
Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

Dome (Mate et al., 1999). And although blue whales are often present in parts of the National Marine Sanctuary waters from June through November, their occurrence and distribution during this feeding period is highly variable. Due to insufficient sightings in the data set (49 sightings of 77 individuals) for the study area, seasonal maps of blue whale density were not generated. Additional sighting data for blue whale will be integrated in Phase 2, and seasonal maps may be generated at that time.

Blue whales feed on seasonally abundant and dense euphausiid (krill) schools in discrete depths in the water column (Benson et al., 2002), concentrated in the deep scattering layer along canyon and shelf-break edges, and in daytime surface swarms of krill (Schoenherr, 1991; Croll et al., 1998; Forney and Barlow, 1998). Spatially, they were widely distributed in shelf-break and slope habitats, as well as seaward of National Marine Sanctuary boundaries, and to a lesser extent, over the shelf. Although not directly shown on this map, blue whales also occur in the Cordell Bank National Marine Sanctuary and off Bodega Bay (Calambokidis et al., 1990b; Calambokidis et al., 1998), as well as in waters around the Farallon Islands (C.Keiper, pers.comm).

There is considerable interchange and interregional movements between Blue whales that occur off southern California (from the Santa Barbara Channel and Southern California Bight) to areas in the Monterey Bay, Gulf of the Farallones, Bodega Bay, and northern California (Calambokidis et al., 1998). In a study of the Monterey Bay area (Benson et al., 2002), occurrence of Blue whales in Monterey Bay was related to seasonal upwelling patterns that affect seasonally abundant, dense (and ephemeral) patches of euphausiids that occur during summer and fall (Benson et al., 2002). See map of SWFSC survey data for blue whale (Figure 77) for greater geographic extent of the range and interannual variations for this species.

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS



ABOUT THESE MAPS

Figures 74a, b and c show the density (animals/km²) of humpback whales in the Upwelling, Oceanic, and Davidson Current seasons, displayed in 10'x10' cells. Densities are based on combined data of several studies (see "Methods" and "Data Sources"). The color and mapping intervals were customized to show the most structure and highlight significant areas, while allowing comparisons among marine mammal species. Cells that were surveyed but which had no humpback whales have a density of zero; unsurveyed areas appear white. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200m and 2,000m isobaths are also shown in blue.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence in the study area, map d shows seasonal high use areas, displayed in 10'x10' cells. This map provides a further synthesis of densities presented in maps a, b and c (see "Methods" for details), and portrays the relative importance of various areas to the species. Areas with consistent high use are highlighted on this map. To provide a relative reference for the "high use" areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there), or present but at lesser concentrations in any particular season.

DATA SOURCES

At-sea densities for cetaceans are based on data from eight survey programs conducted in 1980-2001. These data were combined using CDAS software into the MMS-CDAS data system (MMS, 2001), developed for Minerals Management Service and expanded for this project. Of the data sets on the original CD-ROM, five aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program was still ongoing and data from recent years were added to this data set. In addition, data from three ship-based survey programs were converted to a compatible format for analysis. See section introduction for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (MMS, 2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDF&G-OSPR), unpublished data. Early data were collected using methods described by Bonnell et al. (1983) and Dohl et al. (1983); more recent data were collected using updated technology but with the same general method. Data sources for ship-based survey data include David Ainley, unpublished data (see Oedekoven et al., 2001 for details on methods). Although the at-sea data span the years 1980-2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982

and 1985-2001. For the Oceanic Season, data are from 1980-1982, 1991 and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources"). Cetacean observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into 10'x10' cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of cetaceans of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was censused more than once, densities were averaged, with adjustment made for effort.

Note that these maps represent either sighting locations or densities that used survey strip widths relative to each survey platform (e.g., plane, ship); density was calculated on the basis of the number of animals sighted and area surveyed. The data have only been corrected to normalize for survey effort and to exclude observations with winds greater than 25 knots (smaller or less obvious species are often less detectable even at wind speeds of less than 25 knots). Additional corrections are planned for Phase 2 of this project and are briefly discussed below.

For example, no adjustments or corrections have been made to account for differences in marine mammal detectability among species and differential probability of detecting animals from aerial and shipboard platforms. Individual body size, group size, and species-specific behaviors, such as proportion of time spent submerged, are all factors known to affect detection and hence, observed distribution and density estimates as well. Because of the very different attributes of aerial and shipboard platforms, these factors, and the associated adjustments for observations, vary among the studies. Additional data, mapping and analysis in Phase 2 may provide more definitive spatial patterns for this species.

Map d was developed using the same approach as for maps a, b and c. For each season, the cells with densities in the top 20% of non-zero values were designated "high use" for that season. Cells were scored for "high use" in one, two, or three seasons and are depicted by color. To provide a relative reference for

Figure 74. Maps for humpback whale: seasonal at-sea densities and high use areas.

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

the “high use” areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there) or present (but densities were never in the top 20% for any season). Further detail on methods is provided in the "Data and Analysis" section.

RESULTS AND DISCUSSION

The humpback whale is federally listed as endangered under the Endangered Species Act. The eastern North Pacific stock of the humpback whale that occurs in the study area, feeds off California, Oregon, and Washington and migrates from its breeding and calving areas off coastal Mexico and Central America (Calambokidis et al., 2000). In this study, the humpback whale was the most numerous pelagic baleen whale sighted and was primarily distributed over the shelf, upper slope and some lower slope habitats. Humpback whales are sighted from the Farallon Islands in all months (Pyle and Gilbert, 1996), though they are more frequently sighted off central California from March through November, with peaks in the summer and fall (Calambokidis et al., 1996), a pattern reflected in the seasonal distribution maps.

During the Upwelling Season, humpback whales mostly occurred in the shelf and slope areas of, and adjacent to, the Gulf of the Farallones (GFNMS) and the northern part of Monterey Bay National Marine Sanctuary (MBNMS); see map for other areas. During the Oceanic Season, the CDAS map shows the Humpback whales more concentrated in the areas of the GFNMS, the Cordell Bank National Marine sanctuary (CBNMS), the northwest corner of the MBNMS, and the adjacent slope area; the SWFSC Humpback whale map (Figure 77) shows concentrations over the shelf and slope throughout the study area extent. Densities and sightings for the Davidson season were lowest, but like the other seasons, most occurrences were over the shelf and slope.

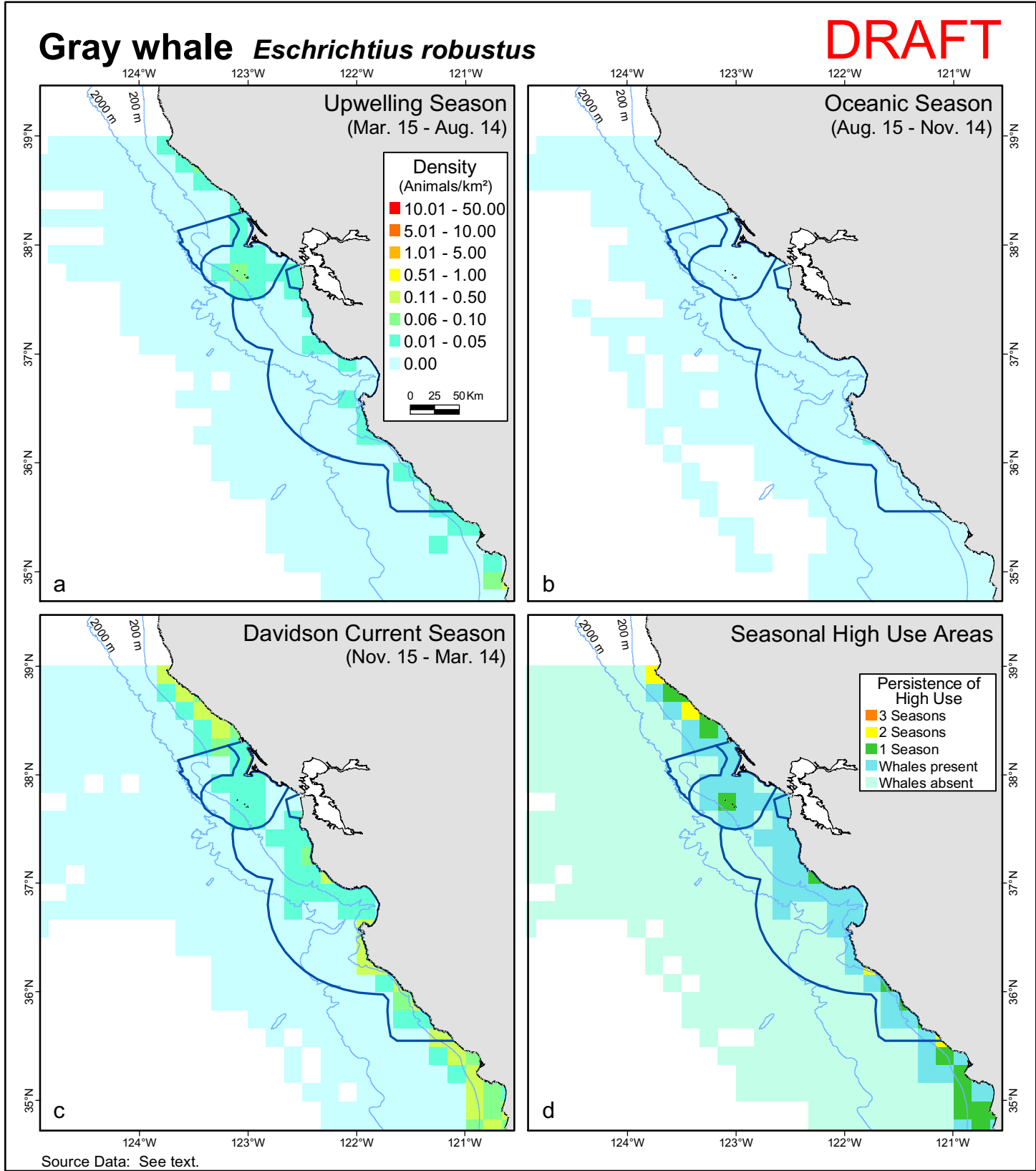
A major food type for humpback whales is euphausiids (krill). The Upwelling Season and beginning of the Oceanic Season is characterized by a seasonal peak in euphausiid density that occurs in July/August but can extend into the Oceanic Season (8/15-11/14). Krill abundance increases one to four months after seasonal peaks in primary production (Croll et al. 1998). One of the dominant species of krill (*Thysanoessa spinifera*) forms dense shoals in the shelf region from Fort Ross south to the Channel Islands (Kieckhefer 1992). Primary feeding sites of humpback whales are located at Monterey Bay (Benson et al., 2002), Bodega Canyon, Cordell Bank, and the Farallon Islands (Kieckhefer, 1992). There is considerable interchange and inter-regional movement of humpback whales within a feeding season between the Santa Barbara Channel, Monterey Bay, and to the north off Eureka (Calambokidis et al., 1996, Calambokidis et al., 1998). During the Davidson Current

Season, most humpback whales are in breeding/calving areas, hence the relatively few sightings in the study area (1980, 1982, and 1993) during this season.

The NOAA/SWFSC stock assessment sightings maps (Figure 78) indicate humpback whales occurred off northern California, and south to Point Conception, with sightings in the CBNMS, GFNMS, and MBNMS during 1993, 1996, and 2001. During the 1996 and 2001 surveys (when effort extended north to Washington), humpback whales were also sighted off Washington and Oregon. Based on CDAS data shown in these maps, most high use areas occurred over the shelf and slope.

Humpback whales feed on seasonally abundant, small schooling fishes (e.g. northern anchovy, Pacific sardine, Pacific herring) and euphausiids (primarily *T. spinifera* and *E. Pacifica*; Kieckhefer, 1992). See map of SWFSC survey data for humpback whale (Figure 78) for additional geographic extent of the humpback whale range and interannual variations for this species.

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS



ABOUT THESE MAPS

Figures 75a, b and c show the density (animals/km²) of gray whales in the Upwelling, Oceanic, and Davidson Current seasons, displayed in 10'x10' cells. Densities are based on combined data of several studies (see "Methods" and "Data Sources"). The color and mapping intervals were customized to show the most structure and highlight significant areas, while allowing comparisons among marine mammal species. Cells that were surveyed but which had no gray whales have a density of zero; unsurveyed areas appear white. Blue lines indicate the National Marine Sanctuary boundaries of Cordell Bank, Gulf of the Farallones, and Monterey Bay; bathymetric contours for the 200m and 2,000m isobaths are also shown in blue.

In order to provide one map for the species that integrates the patterns of its spatial and temporal occurrence in the study area, map d shows seasonal high use areas, displayed in 10'x10' cells. This map provides a further synthesis of densities presented in maps a, b and c (see "Methods" section for details), and portrays the relative importance of various areas to the species. Areas with consistent high use are highlighted on this map. To provide a relative reference for the "high use" areas, cells are also shown where the species were absent (i.e., the cell was sampled but the species was not recorded there), or present but at lesser concentrations in any particular season.

DATA SOURCES

At-sea densities for cetaceans are based on data from eight survey programs conducted in 1980-2001. These data were combined using CDAS software into the MMS-CDAS data system (MMS, 2001), developed for Minerals Management Service and expanded for this project. Of the data sets on the original CD-ROM, five aerial survey data sets contained data in the study area from Point Arena to Point Sal. Of these, the OSPR survey program was still ongoing and data from recent years were added to this data set. In addition, data from three ship-based survey programs were converted to a compatible format for analysis. See "Data and Analyses" subsection in 2.3 for details on individual data sets.

Data sources for aerial at-sea data include MMS-CDAS (2001) and California Department of Fish and Game Office of Spill Prevention and Response (CDF&G-OSPR), unpublished data. Early data were collected using methods described by Bonnell et al. (1983) and Dohl et al. (1983); more recent data were collected using updated technology but with the same general method. Data sources for ship-based survey data include David Ainley, unpublished data (see Oedekoven et al., 2001 for details on methods). Although the at-sea data span the years 1980-2001, data are not available for all seasons in all years. For the Upwelling Season, data are from 1980-1982 and 1985-2001.

For the Oceanic Season, data are from 1980-1982, 1991 and 1994-2001. For the Davidson Current Season, data are from 1980-1986 and 1991-2001.

METHODS

At-sea densities are the result of a synthesis of data from eight shipboard and aerial survey programs conducted in the study area in the years 1980-2001 (see "Data Sources"). Cetacean observation data and trackline data from these studies were converted to a common format. All aerial data were continuous; ship-based data were converted separately into a continuous transect to the extent possible. From the digitized survey data, the distributions of effort and of species were mapped into 10'x10' cells using CDAS, a custom geographic information system for analyzing marine bird and mammal surveys (MMS, 2001). The length and width of the survey trackline in a given cell (estimated trackline width varied by platform, depending on speed and height above water) were used to estimate the area sampled. The number of cetaceans of each species seen in a cell was then divided by the area sampled in the cell to estimate density. If a cell was censused more than once, densities were averaged, with adjustment made for effort.

Note that these maps represent either sighting locations or densities that used survey strip widths relative to each survey platform (e.g., plane, ship); density was calculated on the basis of the number of animals sighted and area surveyed. The data have only been corrected to normalize for survey effort and to exclude observations with winds greater than 25 knots (smaller or less obvious species are often less detectable even at wind speeds of less than 25 knots). Additional corrections are planned for Phase 2 of this project and are briefly discussed below.

For example, no adjustments or corrections have been made to account for differences in marine mammal detectability among species and differential probability of detecting animals from aerial and shipboard platforms. Individual body size, group size, and species-specific behaviors, such as proportion of time spent submerged, are all factors known to affect detection and hence, observed distribution and density estimates as well. Because of the very different attributes of aerial and shipboard platforms, these factors, and the associated adjustments for observations, vary among the studies.

Map d was developed using the same approach as for maps a, b and c. For each season, the cells with densities in the top 20% of non-zero values were designated "high use" for that season. Cells were scored for "high use" in one, two, or three seasons and are depicted by color. To provide a relative reference for the "high use" areas, cells are also shown where the species was absent (i.e., the cell was sampled but the species was not

Figure 75. Maps for gray whale: seasonal at-sea densities and high use areas.

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

recorded there) or present (but densities were never in the top 20% for any season). Further detail on methods is provided in the "Data and Analysis" section.

RESULTS AND DISCUSSION

The eastern population of the gray whale migrates from summer feeding grounds in the Bering, Chukchi, and western Beaufort Seas, south along the west coast of North America to its winter breeding and calving areas off the coast of Baja California. The southward migration includes (in the order of sex and age-class) females in late pregnancy, females that have recently ovulated, adult males, immature females, and lastly, immature males. In the study area, this southward migration generally occurs from December through February and peaks in January. The northward migration generally occurs from February through May and peaks in March and includes (in the order of reproductive condition, sex, age-class,) newly pregnant females, adult males, immature females, and last in this migration, the females with calves. The latter migrate northward through the study area during April and May, and sometimes June. The northward migration is reflected in the distribution patterns during the Upwelling Season, when gray whales are distributed in the coastal and inner/outer shelf habitats throughout the study area, en route to their northern feeding grounds, a pattern reflected in their virtual absence (according to the data set) in the study area during the Oceanic Season.

In the study area and data sets analyzed, the gray whale was the second most numerous baleen whale. Concentrations of this species were greatest during the Davidson Current Season, a period that encompasses both the southward and northward migration, with greatest concentrations observed along the coast near Cypress Point and south of Point Sur to Lopez Point. Relative densities were somewhat greater to the north of CBNMS and to the south of MBNMS (likely related to the timing of individuals moving north or south). Recent preliminary documentation of the southbound migration during 2000 and 2001 indicated population estimates of 17,414 (CV=10%), well below previous (1997/98) estimates of 26,635 (CV=10%; Rugh et al., 2002). These low estimates may have been caused by an unusual number of whales that did not migrate as far south as Granite Canyon (the survey location), or abundance may have declined following the high mortality rates observed in 1999 and 2000 (Rugh et al., 2002).

Strandings along the coast of North America were six times more prevalent than during 1995-1998 (Gulland et al., 2001). Factors that may have contributed to the high number of strandings include: starvation, anthropogenic and natural toxins, infectious diseases, ship strikes, detection effort and reporting, and wind and current effects (Gulland et al., 2001).

Significant declines in calf counts also occurred during this same period (Perryman et al., 2002).

The apparent seasonal high-use areas noted in map d (the Farallon Islands, off Año Nuevo, and north of Cordell Bank near Point Arena and Fort Ross) are likely related to the timing of the migration and may not represent a discrete spatial pattern.

Gray whales feed on benthic invertebrates (e.g. gammarid amphipods; Leatherwood and Reeves, 1983), mysid shrimp, herring eggs/larvae, crab larvae, ghost shrimp (Darling et al., 1998), and surface swarms of euphausiids (Benson et al., 2002). Although most individuals of gray whales in the study area were non-feeding migrants, some individuals do feed on a regular basis near the South Farallon Islands, at the mouth of Tomales Bay and Drakes Bay (S. Allen, 2002, pers. comm.), during their northward migration. Gray whales also feed in San Francisco Bay (in some years: 1999, 2000, -2001; Oliver et al., 2001)) and Monterey Bay (Benson et al., 2002). Gray whales also have been seen regularly off Point Reyes, Tomales Bay, Drakes Bay, and the Farallon Islands during non-migratory periods (S. Allen, pers. comm.).

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

Introduction to the SWFSC Data Set, to be used in Phase II of this Analysis. The following marine mammal maps are based on data from NOAA's marine mammal stock assessment program, conducted by NOAA's Southwest Fisheries Science Center. Maps for three species are included below (and 13 more are on the CD-ROM) to provide the reader with an idea of some of the additional data that will be incorporated into the overall mammal data set and analysis in Phase II (Figures 76-78).

These maps show sightings (species group size), and effort locations generally for the late summer/fall season (data ranged from July-December) for four years: 1991, 1993, 1996 and 2001, off the coasts of California, Oregon and Washington. These maps are the results of broad-scale, ocean ship surveys (aerial surveys are not included), and are used in the development of stock estimates and trend analyses for most marine mammals that occur off the coasts of California, Oregon and Washington. These SWFSC maps do not represent the distribution of the species, but they do provide an indication of the broader spatial extent of the species during the late summer/fall season.

For more information on the marine mammal stock assessment survey data, visit: <http://swfsc.nmfs.noaa.gov/PRD/CMMP/> or contact Dr. Jay Barlow at Jay.Barlow@noaa.gov.

About the SWFSC Dall's Porpoise Maps (Figure 76). These SWFSC maps of surveys conducted in July through early December 1991, 1993, 1996, and 2001, (late upwelling and Oceanic season) encompass a much larger geographic extent and provide an example of the off-shore and northern geographic extent of the Dall's porpoise. A visual comparison of the SWFSC maps among years (1991, 1993, 1996, 2001) indicates occurrence patterns of Dall's porpoise varied; number of sightings was relatively greater off northern California than off central California in 1991, (when survey effort was only off California). In the survey of 1996, (when survey effort extended north to Oregon and Washington), number of sightings and average group size was relatively greater off Oregon and northern California than off central California. Sightings that occurred within NMS boundaries occurred in Monterey Bay and off Point Reyes (when effort extended into these areas). See "Map Text" and "Discussion" in CDAS map section for additional information on Dall's porpoise.

About the SWFSC Blue Whale Maps (Figure 77). These SWFSC maps of surveys conducted in July through early December 1991, 1993, 1996, and 2001, (late upwelling and Oceanic season) encompass a much larger geographic extent than the study area covered with the CDAS maps and indicate concentrations of Blue whales off southern California and further off-shore in pelagic, deep ocean habitats (not shown

in the CDAS maps). A visual comparison of the SWFSC maps among years (1991, 1993, 1996, 2001) indicates occurrence patterns of blue whales varied; relatively greater concentrations of blue whales off southern California were evident in 1991, 1993, and 1996, however, this species was virtually absent (except for a few sightings) in this region during the survey of 2001. Sightings occurred within NMS boundaries (when effort extended into these areas) off Point Reyes in 1991 and 1996, within the Gulf of the Farallones National Marine Sanctuary in 1993, and within Monterey Bay in 1996. See "Map Text" and "Discussion" in CDAS map section for additional information on blue whales.

About the SWFSC Humpback Whale Maps (Figure 78). These SWFSC maps of surveys conducted in July through early December 1991, 1993, 1996, and 2001, (late upwelling and Oceanic season) encompass a much larger geographic extent and indicate concentrations of humpback whales in central California relatively closer to shore. (See SWFSC blue whale maps for comparison) and distributed off northern California and south to Point Conception. A visual comparison of the SWFSC maps among years (1991, 1993, 1996, 2001) indicates occurrence patterns of humpback whales varied; relatively greater concentrations occurred off central California in the survey of 1996, compared to the survey of 1991 (when survey effort was similar off central California). Sightings within the CBNMS, GFNMS, and MBNMS occurred during 1993, 1996, and 2001 (when effort extended into these areas). During the surveys of 1996 and 2001 (when effort extended north to Washington and Oregon), humpback whales also were sighted off Washington and Oregon. See "Map Text" and "Discussion" in CDAS map section for additional information on Humpback whales.

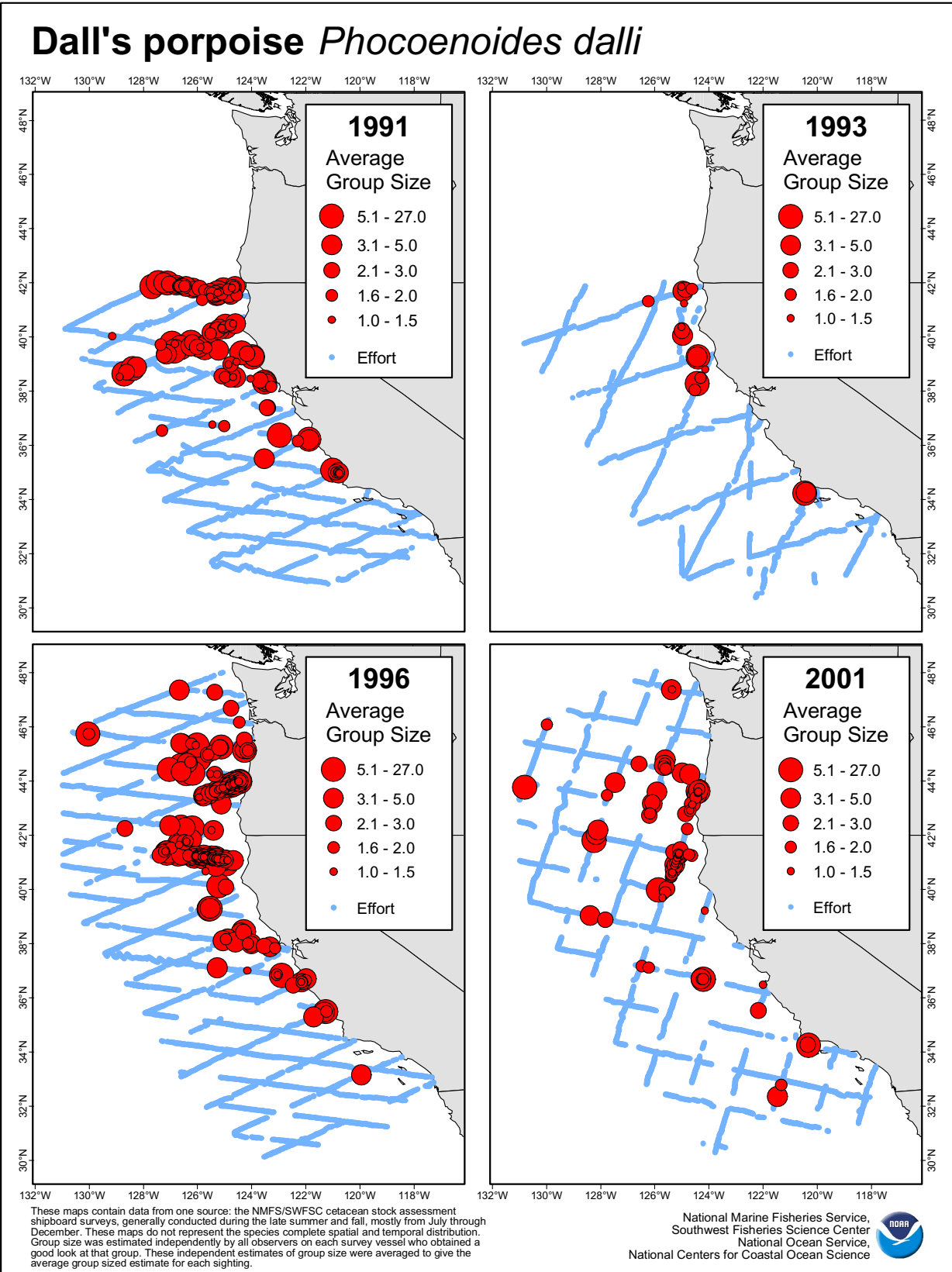


Figure 76. Maps for Dall's porpoise: SWFSC stock assessment data: average group size of sightings and survey effort.

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

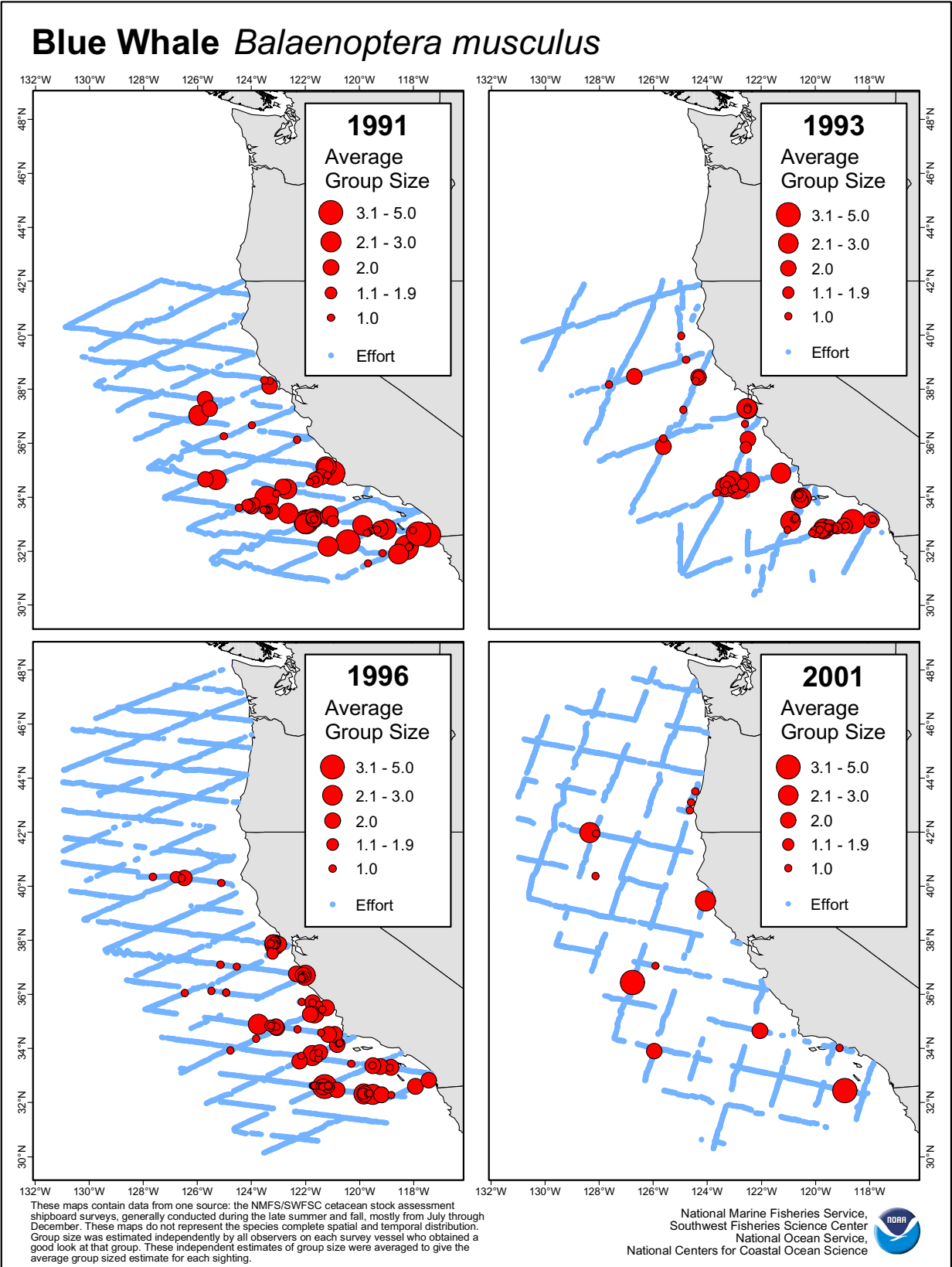


Figure 77. Maps for blue whale: SWFSC stock assessment data: average group size of sightings and survey effort.

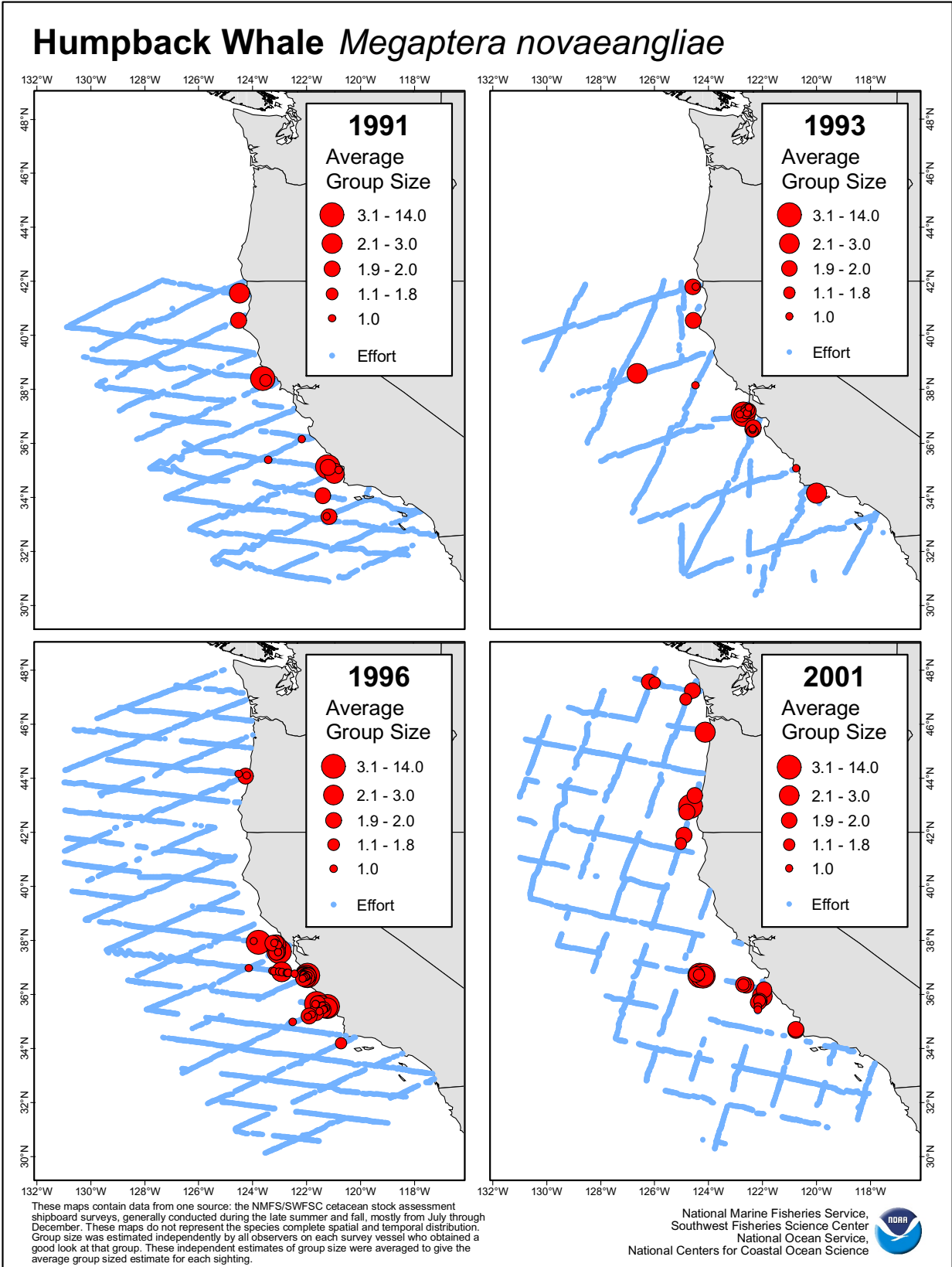


Figure 78. Maps for humpback whale: SWFSC stock assessment data: average group size of sightings and survey effort.

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

SECTION SUMMARY

The marine mammal fauna of the study area include species with a variety of spatial and temporal patterns and can be generally characterized as:

- resident, breeding species that occur year-round (e.g. harbor seal, southern sea otter, Steller sea lion);
- species that breed, pup, and molt in the study area and then as adults, feed elsewhere (e.g. northern elephant seals);
- species that are seasonally abundant during their migration (e.g. gray whale);
- seasonally abundant species that have either migrated to these waters to forage during summer and fall (e.g. humpback and blue whales) or to forage during winter (e.g. northern fur seal and California sea lions); and
- species which, though present year-round, exhibit highly variable seasonal shifts in distribution (e.g. several species of dolphins and porpoises).

Preliminary CDAS maps for 13 species were developed for this document; this is fewer than half of the mammal species in the study area and the maps are draft. No summary analyses across mammal species were done, as they would be inconclusive, and biased by the limited number and type of species mapped (e.g., coastal, offshore).

However, preliminary data products do show that marine mammals of the study area are widely distributed from the shore to deep ocean, and while some species are found mostly over the shelf, or deep offshore, most species occur over a variety of bathymetric zones. Given that the data and maps are preliminary and most likely incomplete, it is not possible at this time to evaluate the importance of smaller, discrete areas for the mammal species listed.

The broad-scale spatial coverage of the 16 maps for cetaceans from the NMFS/SWFSC marine mammal stock assessment program (Barlow, unpublished data), provided additional information for 13 species that were distributed in deep ocean habitats, and well beyond the range of the current CDAS data set. These data will likely be incorporated into the CDAS data set and mammal analysis planned for Phase II.

The marine mammal life history information and analytical map products were used to develop the summary spatial and temporal distributions described below.

Life History Characteristics

Table 25 is an initial summary of life history and management information that was identified in the marine mammal mapping analyses. This table will be expanded in Phase II.

Associations with Bathymetric Areas

Marine mammal distributions can be associated with bathymetrically-defined areas and results include:

- Widely distributed (found throughout the study area): Dall’s porpoise and northern fur seal (but mostly occurs over the slope and in the deep ocean); California sea lion, (but mostly occurs along the coast and over the inner shelf); and northern elephant seal and Steller sea lion.
- Coastal: Southern sea otter, gray whale (but this species also occurs throughout the broad shallow shelf of the Gulf of the Farallones and in proximity of the Farallon Islands).
- Inner Shelf: Southern sea otter, California sea lion, Steller sea lion, harbor seal, humpback whale and gray whale.
- Outer Shelf: California sea lion, Steller sea lion, harbor seal, northern elephant seal, northern fur seal, Pacific white-sided dolphin, blue whale, humpback whale and gray whale.
- Slope: California sea lion, northern elephant seal, Northern fur seal, Dall’s porpoise, Pacific white-sided dolphin, Risso’s dolphin, northern right whale dolphin, blue whale and humpback whale.
- Deep Ocean: California sea lion, northern fur seal, northern elephant seal, Dall’s porpoise, Pacific white-sided dolphin, Risso’s dolphin, northern right-whale dolphin, blue whale, and humpback whale.

Occurrence by Oceanographic Season

The seasonal occurrence patterns of marine mammals in waters off north/central California were clearly evident for migrating species of large cetaceans (gray, blue and humpback whales) and for the non-breeding pinnipeds that

Table 25. Preliminary life history and management information for selected marine mammals off north/central California.

Common Name	Scientific Name	Protection & Population Status		Occurrence & Breeding in Study Area			Prey Types					
		Protection Status in Study Area (FE, FT, SE, ST)	Population Trend of Population in the Study Area (Increasing, Decreasing, Relatively Stable, Unknown)	Temporal Occurrence	Time Period of Primary Occurrence in Study Area (months)	Breeding Time Period (months)	Benthic Invertebrates	Plankton	Euphausiids (krill)	Other Pelagic Invert's (e.g. squid, octopus)	Fishes	Other Vertebrates
Southern sea otter	<i>Enhydra lutris nereis</i>	Federally Threatened	Declining ¹	Year-round	All months	June/July - Oct/Nov	X			X		
California sea lion	<i>Zalophus californianus</i>		Increasing ²	Present year-round; seasonally abundant	Aug-Mar	May-July				X	X	
Steller sea lion	<i>Eumetopias jubatus</i>	Federally Threatened	Año Nuevo: possibly stable last 3 yrs ³ ; Farallones: declining ⁴	Year-round	All months	mid-May to mid-July				X	X	
Harbor seal	<i>Phoca vitulina richardsi</i>		Stable (California net production may be slowing) ²	Year-round	All months	Mar-June				X	X	
Northern elephant seal	<i>Mirounga angustirostris</i>		Año Nuevo: Stable, last 5 yrs ³ ; Farallones: declining ⁵ ; Pt. Reyes Headlands: increasing ⁶ ; California: net productivity rate declining ^{2a} ; number pups appears to be leveling off ^{2a}	Present year-round; seasonally abundant	At-sea - unknown at this time; at rookeries - Nov-Mar	mid-Dec thru mid-Mar				X	X	
Northern fur seal	<i>Callorhinus ursinus</i>		San Miguel Island stock: increasing ² ; Pribilof Is: rate of increase 8.12% ⁷	Present year-round; seasonally abundant	Feb-May	June-July				X	X	
Dall's porpoise	<i>Phocoenoides dalli</i>		Trends Unknown ²	Year-round	No trend apparent in data	Unknown				X	X	
Harbor porpoise (Northern CA, San Francisco/Russian River, Monterey stocks)	<i>Phocoena phocoena</i>		N. California stock: No Trends ^{2a} ; San Francisco/Russian River and Monterey stock: trends in relative abundance not statistically significant. ^{2a}	Year-round	Unknown at this time	Unknown				X	X	
Pacific white-sided dolphin	<i>Lagenorhynchus obliquidens</i>		No Trends ²	Year-round	No trend apparent in data	Unknown				X	X	
Risso's dolphin	<i>Grampus griseus</i>		Trends Unknown ²	Year-round	No trend apparent in data	Unknown				X	X	
Bottlenose dolphin (California coastal stock)	<i>Tursiops truncatus</i>		Stable ²	Year-round	No trend apparent in data	N/A				X	X	
Short-beaked common dolphin	<i>Delphinus delphis</i>		Stock status unknown; likely distributional shifts rather than population increase ²	Not detected in CDAS data	No trend apparent in data	Unknown				X	X	
Northern right whale dolphin	<i>Lissodelphis borealis</i>		Trends Unknown ²	Year-round	No trend apparent in data	Unknown				X	X	
Killer whale	<i>Orcinus orca</i>		Trends Unknown ²	Year-round	No trend apparent in data	Unknown				X	X	X
Baird's beaked whale	<i>Berardius bairdii</i>		Trends Unknown ²	Unknown	Insufficient data	N/A				?	?	
Beaked Whales (Mesoplodonts)	<i>Mesoplodond spp.</i>		Trends Unknown ²	Unknown	Insufficient data	N/A				?	?	
Cuvier's beaked whale	<i>Ziphius cavirostris</i>		Trends Unknown ²	Unknown	Insufficient data	N/A				?	?	
Sperm whale	<i>Physeter macrocephalus</i>	Federally Endangered	Trends Unknown ²	Seasonal	No trend apparent in data	N/A				X		
Blue whale	<i>Balaenoptera musculus</i>	Federally Endangered	Increasing? ⁸	Seasonal	Aug-Nov	N/A			X		X?	
Humpback whale	<i>Megaptera novaeangliae</i>	Federally Endangered	Increasing 6-7%/yr ⁹	Present year round; seasonally abundant	June-Nov	N/A				X	X	
Fin whale	<i>Balaenoptera physalus</i>	Federally Endangered	Trends Unknown ²	Seasonal	Aug-Nov	N/A			X		X	
Minke whale	<i>Balaenoptera acutorostrata</i>		Stock status unknown; no data on trends ²	Year-round	No trend apparent in data	N/A			X		X	
Gray whale	<i>Eschrichtius robustus</i>	Delisted Federal 1994	Increasing to late 1990's; Decreasing (2002) ¹⁰	Present year round; seasonally abundant	Dec-Apr	Dec-Jan (breeds off Baja)	X	X	X			

Notes

1. This table is preliminary; in Phase II more information will be added and the table will be reviewed by experts.

2. A question mark (?) in the table indicates the entry is a probable entry (e.g., prey type); these items may be further evaluated in Phase II.

3. Superscripts indicate sources as follows: 1-USGS, 2002; 2-Carretta et al.; 2001; 2a-Carretta et al. 2002; 3-P.Morris pers.comm., credited to B. Le Boeuf; 4-Hastings and Sydeman, 2001; and 5-USFWS, 2000.

6-Sydeman and Allen, 1999; 7-Gerrodette et al.,1985; 8-Calambokidis pers.comm.; 9-Forney et al., 2000; 10-Rugh et al., 2002

4. All marine mammal species have legal protection under the Marine Mammal Protection Act of 1972; species identified as Federally Endangered (FE), Federally Threatened (FT) are identified.

No marine mammal species have designation as state endangered (SE) or state threatened (ST) in the California at this time.

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

breed mostly outside the study area (northern fur seal and California sea lion). The species occurrences in the three oceanographic seasons are described below.

Upwelling Season (~Spring/Summer). This season is characterized by an increase in cold, nutrient-rich water brought to the surface by persistent northwest wind and the Coriolis effect, followed by intermittent relaxation of upwelling. Within-season variability during the upwelling process affects food web development and the availability of prey to marine mammals.

The Upwelling Season is also characterized by variations and fluctuations in seasonal peaks in abundance of small schooling fish and relative densities of euphausiids. The humpback whale was present in greater abundance during the Upwelling and Oceanic seasons. Humpback whales migrate to waters off north/central California to feed on seasonally-abundant prey.

The northern fur seal also was relatively abundant during the Upwelling and Davidson Seasons. After the breeding/pupping season (June-July), adult females and juveniles migrate from rookeries on San Miguel Island in the southern California Bight (the San Miguel Island stock) and from the Eastern Pacific stock of the Pribilof Islands and are therefore relatively abundant in the study area during winter and early spring.

Oceanic Season (~Autumn). During the Oceanic Season, the northwest winds subside, warmer offshore water is advected onshore, thermoclines strengthen, ocean conditions become more stratified and marine mammal prey become more stabilized. The following four species were relatively more abundant during the Oceanic season (evaluated by the visual inspection of the maps): Pacific white-sided dolphin, blue whale, humpback whale, and California sea lion. Although the Pacific white-sided dolphin occurred during all seasons, it appeared to be more numerous during the Oceanic Season. The blue whale (like the humpback whale) migrates to north/central California to forage on seasonally-abundant euphausiids during summer and fall. The California sea lion, the most abundant pinniped in the study area was present year-round, however, greater numbers of sea lions were present during the Oceanic season (just after the breeding season), but also during the Davidson Season (before the next breeding season).

Davidson Current Season (~Winter). The Davidson Current Season is characterized by frequent winter storms, downwelling, relatively warm uniform temperature to considerable depths and a deep mixed layer. During this season, the gray whale was relatively abundant because it migrates through the study area on its way south (or north) during this period. The northern fur

seal and California sea lion also were relatively abundant (see comments on the Upwelling and Oceanic seasons above).

Additional Observations. No clear seasonal patterns could be determined in this preliminary visual assessment for the smaller cetaceans: northern right-whale dolphin, Dall's porpoise, Pacific white-sided dolphin and Risso's dolphin. For the latter two species, however, a shift in distribution was evident during the Oceanic season; see Figures 69 and 70. Given the highly variable distribution of the smaller cetaceans, shifts in distribution (as indicated on the maps) may not indicate a seasonal pattern.

Elephant seals, Steller sea lions, and harbor seals were present in National Marine Sanctuary waters year-round. And although at-sea sightings are relatively infrequent, these species are frequently sighted at haulouts and rookeries at specific times of the year, as noted in Table 25. Important at-sea time periods for these infrequently-sighted species is inconclusive due to insufficient at-sea data and differences in behavior that affect sighting frequency and otherwise low abundance. For example, some of these sighting issues include: at-sea sightings typically consist of single individuals or small groups of two or three; elephant seals are rarely at the surface; and Steller sea lions are a threatened species and thus occur in small numbers.

Overview of Occurrence Patterns

Cetaceans. Cetaceans were found throughout the study area; in coast, shelf, upper/lower slope and deep ocean habitats.

- The humpback whale was the most numerous pelagic baleen whale seen in the study area and was seen more frequently during the Upwelling and Oceanic Seasons. Seasonal high use areas within the Gulf of the Farallones National Marine Sanctuary were regions around the Farallon Islands and to the west of the islands, on the outer shelf and upper slope, regions over Pioneer, Ascension and Monterey canyons. Given the highly variable distribution of humpback whales in the study area during the feeding season, observed spatial distribution may not indicate a general spatial pattern.
- The gray whale was the second most abundant baleen whale and was found in coastal and shelf regions; relative abundance of the gray whale in the study area was greater during the Upwelling and Davidson Current Seasons that coincided with the north and south migration of this species. Seasonal high use areas were to the north of Cordell Bank National Marine Sanctuary near Point Arena. Given the variable distribution of the gray whale, relative to the timing of the migration, this observed spatial distribution may not indicate a general spatial pattern.

• The Pacific white-sided dolphin was the most numerous of the small cetaceans and appeared to be more abundant during the Oceanic Season in the Gulf of the Farallones and Monterey Bay National Marine Sanctuaries; seasonal high use areas were upper/lower slope regions in the Monterey Bay and Cordell Bank National Marine Sanctuary. Given the highly variable distribution of the Pacific white-sided dolphin, the observed spatial and temporal distribution may not indicate a general spatial/temporal pattern.

• The northern right whale dolphin was the second most numerous of the small cetaceans; concentrations appeared to be greater within the Monterey Bay National Marine Sanctuary, as well as outside National Marine Sanctuary boundaries. Seasonal high use areas were upper/lower slope regions in the Monterey Bay National Marine Sanctuary. No seasonal pattern in relative abundance was visually detected in the maps; however, a seasonal shift in the distribution of this species in the study area was apparent during the Oceanic Season (concentrations were greater outside than within National Marine Sanctuary boundaries); during the Davidson Season the greatest concentrations occurred in the southern regions of the Monterey Bay National Marine Sanctuary. Given the highly variable distribution of the northern right whale dolphin, the observed occurrences may not indicate a general spatial/temporal pattern.

• Risso's dolphin was the third most numerous of the small cetaceans and occurred in shelf, and upper/lower slope habitats. This species was more widespread during the Upwelling Season and more concentrated in the southern portion of the study area (within and outside National Marine Sanctuary boundaries) during the Oceanic and Davidson Current Seasons. No clear seasonal shift in relative abundance in the study area was detected in a visual inspection of maps. Seasonal high use areas were in the Monterey Bay National Marine Sanctuary over slope/canyon habitats. Given the highly variable distribution of the Risso's dolphin, the observed spatial and temporal distribution may not indicate a general spatial/temporal pattern.

• The Dall's porpoise was the fourth most numerous small cetacean and distribution was widespread on shelf, upper/lower slope, and deep ocean habitats. No clear seasonal pattern in relative abundance in the study area was visually detected in the maps. Seasonal high use areas were upper slope in the Cordell Bank and Gulf of the Farallones National Marine Sanctuaries. Given the highly variable distribution of the Dall's porpoise, the observed occurrences may not indicate a general spatial/temporal pattern.

Pinnipeds. Pinnipeds were found in the coast, shelf, slope and deep ocean habitats of the study area.

• The California sea lion was the most numerous pinniped seen in the study area and occurred throughout the region in coastal, shelf, and upper slope habitats. This species was most abundant during the Oceanic (just after its breeding period) and Davidson Current Season (before its next breeding period) Seasons. Seasonal high use areas were in proximity to major haulout sites near Año Nuevo and the Farallon Islands. Seasonal trends in relative abundance and attendance at haulout sites were associated with warm-water periods (El Niño events); sea lions were more numerous both at-sea and on land during these warm-water periods.

• The northern fur seal was the second most numerous pinniped seen in the study area and occurred in outer shelf, upper/lower slope and deep ocean habitats. Although seen in all seasons, this species was most abundant during the Upwelling and Davidson Current Seasons (non-breeding period), a pattern that coincided with their migration to north/central California from San Miguel Island and the Pribilof Islands. Seasonal high use areas were outside (to the west and north) of National Marine Sanctuary boundaries.

• The northern elephant seal was the third most numerous pinniped seen in the study area, however, sightings were too infrequent to determine seasonal trends in at-sea distribution. Sightings occurred throughout the study region in shelf, upper/lower slope and deep ocean habitats.

• The harbor seal was the fourth most numerous pinniped seen in the study area, however sightings were too infrequent to determine seasonal trends in at-sea distribution. Sightings occurred in coastal and shelf habitats.

• The Steller sea lion was sighted rarely, therefore no seasonal trends in at-sea distribution could be determined. Sightings of this species occurred in coastal, shelf and upper slope habitats.

A Fissiped. The southern sea otter is the only fissiped included in the analysis. This species occurs year-round mostly along the coast and inner shelf. Due to insufficient data no spatial/temporal trends could be determined.

Preliminary Observations of Species Distributions Relative to National Marine Sanctuary Boundaries

• Eight of the 13 marine mammals evaluated in this assessment are relatively pelagic, far-ranging marine mammals that are widely distributed, and are either species that occur mostly in deep ocean habitats (northern fur seal, northern elephant

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

<p>seal, the endangered humpback and blue whales, Dall's porpoise, Risso's dolphin), or over upper/lower slope habitats (northern right-whale dolphin, Pacific white-sided dolphin). All occur both in and outside of the National Marine Sanctuary boundaries of the study area.</p> <ul style="list-style-type: none">• The gray whale also occurs outside National Marine Sanctuary boundaries, but migrates through sanctuary waters along the coast and over the continental shelf.• To the north of Cordell Bank (within relatively close proximity to that National Marine Sanctuary boundary), the Pacific white-sided dolphin, humpback whale, Dall's porpoise, and northern fur seal were present. A relatively high seasonal use area for the gray whale also occurred north of Cordell Bank National Marine Sanctuary. Given the general variable nature of cetacean distributions, these observations are preliminary and may not indicate a spatial pattern.• Relatively high seasonal use areas of the Dall's porpoise, humpback whale and blue whale were located seaward or west of the Gulf of the Farallones National Marine Sanctuary over the lower slope. Given the highly variable distribution of these species, these observations are preliminary and may not indicate a spatial pattern.• Seasonal high use areas of the northern fur seal, northern right whale dolphin, and Risso's dolphin occurred seaward of the Monterey Bay National Marine Sanctuary (western areas of the Monterey Canyon and the Shepard's Meander). Given the highly variable distribution of these species, these observations are preliminary and may not indicate a spatial pattern.• Seasonal high use areas of Risso's dolphin, northern fur seal, and Pacific white-sided dolphin also were located seaward of the southern regions of the Monterey Bay National Marine Sanctuary (near Lucia Canyon and to the south). Given the highly variable distribution of these species, these observations are preliminary and may not indicate a spatial pattern.• Within the study area, haulout sites for the northern elephant seal all occurred within National Marine Sanctuary boundaries. Haulout sites for the harbor seal, California sea lion and Steller sea lion also occurred within National Marine Sanctuary boundaries, but also both north (Steller sea lion, California sea lion, harbor seal) and south (California sea lion, harbor seal) of the boundaries. Harbor seal haulouts occurred along the coast from Point Arena to Point Sal.	<ul style="list-style-type: none">• Rookeries for the northern elephant seal, Steller sea lion and California sea lion occurred within National Marine Sanctuary boundaries of the study area, however, during the El Niño of 1998, California sea lion rookeries were located at Lion rock and Point Sal Rock, to the south of National Marine Sanctuary boundaries. Haulout sites (n=3) for the threatened Steller sea lion are located along the coast to the north of Cordell Bank National Marine Sanctuary.• Southern sea otters occurred in coastal shelf waters, almost exclusively in Monterey Bay National Marine Sanctuary and to the south, outside of the study area to San Nicholas Island in the southern California Bight. <p>DISCUSSION</p> <p>Differences in habitat use relative to large bathymetric features are likely related to factors such as the distribution, abundance, and availability of various prey (species/sizes). Therefore, the importance of the study area must be considered in the context of the variability of ocean climate and oceanography, which strongly affects prey availability.</p> <p>Cordell Bank, the Gulf of the Farallones, and Monterey Bay National Marine Sanctuaries encompass some of the most productive waters along the California coast. Presence of marine mammals in these waters is affected not only by bathymetric features, but also changing oceanographic conditions that result in fluctuations in abundance and distribution of patchily distributed prey. The unique bathymetric features, coupled with the complex physical oceanography off central California play an important role in the distribution of marine mammal prey and, in turn, the distribution of mammals themselves.</p> <p>This unique combination of both wide and narrow continental shelf, areas of high topographical relief (canyon edges, steep slopes, ridges, banks, shelf breaks, seamounts), and the distinctive oceanographic features associated with seasonal upwelling (e.g., upwelling plumes, fronts, temporal and spatial variation in thermocline depth, surface and subsurface currents and eddies) affect the distribution patterns of organisms at many trophic levels. For example, large concentrations of small schooling fishes and euphausiids (krill) that are maintained by the seasonally high primary productivity (supported by seasonal coastal upwelling), often occur along canyons, shelf-breaks, seamounts, and downstream of upwelling centers located at Point Arena, Point Reyes, Point Año Nuevo, and Point Sur, features that also are important areas for both large and small cetaceans.</p> <p>Marine mammals are highly mobile marine predators that feed on a great diversity of prey and are attracted to regions of seasonally abundant high prey densities. Resident marine</p>	<p>mammals (e.g. harbor seals) feed on locally available and seasonally abundant invertebrates or fish in relative proximity to their breeding/pupping/haulout sites, whereas the seasonal migrants (e.g. humpback and blue whales) forage on seasonally available krill or fish, a pattern reflected in their relative abundance during the Upwelling and Oceanic seasons.</p> <p>Response to Short-Term Changes in Climate. Although it is likely that short periods of unusually warm or cold waters affect migratory species and shorter-ranging more resident species, it was not possible to determine effects of these events during this preliminary assessment. Distributional responses to the extremes of climate (e.g. El Niño vs La Niña) may be confounded by: 1) issues associated with comparing different data sets without application of correction factors, 2) small at-sea populations and therefore small sample size for some species (e.g. elephant seals, harbor seals), 3) far-ranging, migratory species being affected outside of the study area, 4) demographic lags to species' responses, 5) variable effects on different marine mammal prey, and 6) behavioral differences among species.</p> <p>Nevertheless, the California sea lion provides an example of a species shift in distribution in response to changing oceanographic conditions. The relative increase in at-sea abundance during El Niño 1986-87, 1992-93, and 1997-98 (not presented in maps; see studies below), likely reflected a greater than usual influx of individuals in response to a reduction in food off southern California (see Trillmich and Ono, 1991; Allen, 1994; Keiper, 2001; Keiper et al., <i>In Review</i>). The greater numbers of sea lions at sea coincided with greater numbers that occurred at haulout sites in the study area. For example, an influx of immature sea lions hauled out at Double Point and at Point Reyes Headlands (per. comm S. Allen) during El Niño, as was also true at the Farallon Islands (Sydeman and Allen, 1999).</p> <p>In summary, seasonal and interannual processes in the ocean climate affect variability in ocean conditions and food web development, and thus, the spatial and temporal occurrence patterns of marine mammals are strongly linked to the physical and biological processes that affect their prey.</p> <p>Phase II Marine Mammal Assessment. This section provides preliminary results of the mammal analyses. The maps presented here provide a preliminary estimate of the mammal species spatial and temporal use of the study area. In Phase II, additional data and analysis will likely yield revised maps for the existing species and additional maps for other species. Some of the data sets for marine mammals have only recently been received and require further processing before species distribution maps can be developed in the GIS. Phase II of this</p>	<p>analysis will address the following factors:</p> <ul style="list-style-type: none">• differences in survey methodology (e.g. line transect vs. strip transect);• differences in the detectability of pinnipeds, small and large cetaceans, and effects of group size;• differences in time spent underwater; and• differences in environmental conditions (e.g. sea state and other weather conditions). <p>Major tasks for Phase II are as follows:</p> <ol style="list-style-type: none">1. Complete the acquisition of data sets for the marine mammals from institutions already contacted (see partial list in No. 2 below).2. Continue working with marine mammal experts, and determine appropriate methods required to analyze additional data sets and apply appropriate correction factors. At a minimum, these data sets will include: sighting data from John Calambokidis at Cascadia Research, and the marine mammal stock assessment program data from NOAA's Southwest Fisheries Science Center.3. Develop a composite marine mammal data set and maps of occurrence patterns for additional mammal species, as well as summary maps and analyses across species, for seasons and other selected time periods. Asemblage analyses may be done to identify spatial/temporal species groups.4. Complete a report on the mammal analyses that will address survey data for 14-23 marine mammal species and related summary mammal maps (e.g., a composite rookery and haulout map, spatial and temporal summaries of at-sea occurrence data across selected mammal groups, and assemblage analyses).5. Conduct an expert review of the maps and report and incorporate necessary revisions. <p>MAJOR SECTION CONTRIBUTORS</p> <p>Glenn Ford, Carol Keiper, Janet Casey, David Ainley, Sarah Allen, Mark Lowry, Tracy Gill, Ken Buja and Wendy Williams.</p> <p>REVIEWERS</p> <p>The following institutes and people participated in the initial map review in October 2002:</p> <p>Sarah G. Allen, Point Reyes National Seashore, Nat'l Park Service</p> <p>Scott Benson, NMFS/Southwest Fisheries Science Center</p> <p>Jay Barlow, NMFS/Southwest Fisheries Science Center</p> <p>Nancy Black, Monterey Bay Whale Watch Institute</p>
--	--	--	--

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

Don Croll, University of California, Santa Cruz
Karin Forney, NMFS/Southwest Fisheries Science Center
Mark S. Lowry, NMFS/Southwest Fisheries Science Center
Michelle Staedler, Monterey Bay Aquarium
Jan Roletto Research Coordinator, GFNMS/CBNMS
And several other members of the NOAA project team and sanctuary programs.

PERSONAL COMMUNICATIONS

Sarah Allen, Point Reyes National Seashore,
U.S. National Park Service
Jay Barlow, Southwest Fisheries Science Center, NOAA
Joelle Buffa, U.S. Fish and Wildlife Service
John Calambokidis, Cascadia Research
Karin Forney, Southwest Fisheries Science Center, NOAA
Denise Greig, The Marine Mammal Center
Mike Harris, California Department of Fish and Game
Brian Hatfield, U.S. Geological Survey
Mike Kenner, California Department of Fish and Game
Mark Lowry, Southwest Fisheries Science Center, NOAA
Pat Morris, University of California, Santa Cruz
Joe Mortenson, Gulf of the Farallones National Marine
Sanctuary, Friends of Marine Sanctuaries Association
Bob Read, California Department of Fish and Game
Michelle Staedler, Monterey Bay Aquarium
William Sydeman, PRBO Conservation Science

REFERENCES

Allen, S.G. 1994. The distribution and abundance of marine birds and mammals in the Gulf of the Farallones and adjacent waters. PhD. Dissertation UC Berkeley.

Allen, S.G. , D. Press, S. Waber. 2002. Long term monitoring of harbor seals at Point Reyes National Seashore, Point Reyes California 5 year Annual Report. National Park Service Technical Report. Washington, D.C. 41 pp.

Antonelis, G.A., Jr., M.S. Lowry, D.P. DeMaster, and C.H., Fiscus. 1987. Assessing northern elephant seal feeding habits by stomach lavage. Mar. Mam. Sci., Vol. 3, pp. 308-322.

Barlow, J. Unpublished data. Cetacean Stock Assessment Ship Survey Data from the Summer and Fall of 1991, 1993, 1996 and 2001. Coastal Marine Mammal Program, Southwest Fisheries Science Center, 8604 La Jolla Shores Dr., La Jolla, CA 92037. Jay.Barlow@noaa.gov <http://swfsc.nmfs.noaa.gov/prd/cmmp/>

Barlow, J. 1995. The abundance of cetaceans in California waters. Part I: Ship surveys in summer and fall of 1991. Fish. Bull. Vol. 93, pp. 1-14.

Barlow, J. 1988. Harbor porpoise, *Phocoena phocoena*, abundance estimation for California, Oregon and Washington: I. Ship surveys. Fish. Bull., US, Vol. 86(3), pp. 417-32.

Barlow, J., Oliver, C.W., Jackson, T.D. and Taylor, B.L. 1988. Harbor porpoise, *Phocoena phocoena*, abundance estimation for California, Oregon, and Washington: II. Aerial surveys. Fish. Bull., US, Vol. 86(3), pp. 433-44.

Barlow, J. and D. Hanan. 1995. An assessment of the status of harbor porpoise in central California. Rept. Int. Whal., Special Issue Vol. 16, pp. 123-140.

Barlow, J. and T. Gerrodette. 1996. Abundance of cetaceans in California waters based on 1991 and 1993 ship surveys. NOAA Tech. Memo NOAA-TM-NMFS-SWFSC-205. La Jolla, CA. 68 pp.

Benson S.R., D.A. Croll, B.B. Marinovic, F.P.Chavez, J.T. Harvey. 2002. Changes in the cetacean assemblage of a coastal upwelling ecosystem during El Niño 1997-98 and La Niña 1999. Prog. in Ocgrphy, Vol. 54, pp. 279-291.

Byrd, B. Abundance, distribution, food habits, and prey availability of the harbor porpoise (*Phocoena phocoena*) in northern Monterey Bay, CA. M.S. Thesis, Moss Landing Marine Laboratories, Stanislaus California State University. 159 pp.

Black, N.A. 1994. Behavior and ecology of Pacific white-sided dolphins (*Lagenorhynchus obliquidens*) in Monterey Bay, California. MS thesis, Moss Landing Marine Laboratories, San Francisco State University CA. 111 pp.

Bonnell, M.L., M.O. Pierson and G.D. Farrens. 1983. Pinnipeds and sea otters of central and northern California, 1980-1983: Status, abundance and distribution. Final report prepared by Center for Marine Studies, University of California, Santa Cruz, for the Minerals Management Service, Contract 14-12-00. OCS Study MMS 84-0044. Santa Cruz, CA. 82 pp.

Bonell, M. L., M.O. Pierson, and G.D. Farrens. 1983. Pinnipeds and Sea Otters of Central and Northern California, 1980-1983: Status, Abundance, and Distribution. Part of Investigator's Final Report, Marine Mammal and Seabird Study, Central and Northern California, Contract No. 14-12-0001-29090. Prepared by Center for Marine Sciences, University of California, Santa Cruz, for the Pacific OCS Region, Minerals Management Service. OCS Study MMS 84-0044. Santa Cruz, CA. 220 pp.

Bonnell, M.L. and R.G. Ford. 1987. California sea lion distributions: A statistical analysis of aerial transect data. J Wildl. Manage. Vol. 51(1), pp. 13-20.

Calambokidis, J., J.C. Cubbage, H.H. Steiger, K.C. Balcomb, P.Bloedel. 1988. Humpback whale (*Megaptera novaeangliae*) distribution and abundance in the Gulf of the Farallones, 1987 Annual Report to Point Reyes National Seashore NPS and Gulf of the Farallones National Marine Sanctuary NOAA. NFMS. La Jolla, CA. 74 pp.

Calambokidis, J., J.C. Cubbage, G.H. Steiger, K.C. Balcomb, and P. Bloedel. 1990a. Population estimates of humpback whales in the Gulf of the Farallones, California, Report to the International Whaling Commission, Vol. 12, pp. 325-333

Calambokidis J. G.H. Steiger, J.C. Cubbage, K.C.Balcomb, C.Ewald, S. Kruse, R. Wells, and R. Sears. 1990b. Sightings and movements of blue whales off central California 1986-88 from photo-identification of individuals. Report to the International Whaling Commission, Vol. 12, pp. 343-348.

Calambokidis, J., T. Chandler, K. Rasmussen, G.H. Steiger, L. Schlender. 1998. Humpback and blue whale photographic identification: report on research in 1997. Report to Southwest Fisheries Science Center, NMFS, La Jolla, California. 36 pp.

Calambokidis, J. G.H. Steiger, K. Rasmussen, J.H. Urban R, K.C. Balcomb, P. Ladron de Guevara P, M. Salinas Z, J.K. Jacobsen, C.S. Baker, L.M. Herman, S. Cerchio and J.D. Darling. 2000. Migratory destinations of humpback whales that feed off California, Oregon and Washington. Mar. Ecol. Prog. Ser., Vol. 192, pp. 295-304.

Calambokidis, J. G.H. Steiger, J.R.Evenson, K.R. Flynn, K.C. Balcomb, D.E. Claridge, P. Bloedel, J.M. Straley, C. S. Baker, O. von Ziegesar, M. E. Dahlheim J.M. Waite, J.D. Darling, G. Ellis and G.A. Green. 1996. Interchange and isolation of humpback whales off California and other north Pacific feeding grounds. Mar. Mam. Sci., Vol. 12(2), pp. 215-226.

Carretta, J.V., J. Barlow, K.A. Forney, M.M. Muto and J. Baker. 2001. U.S. Pacific marine mammal stock assessments: 2001, U.S. Dept Commerce, NOAA-NMFS-SWFSC, NOAA Tech Memo NOAA-TM-NMFS-SWFSC-317. La Jolla, CA. 209 pp.

Carretta, J.V., M.M. Muto, J. Barlow, J. Baker. Draft U.S. Pacific marine mammal stock assessments 2002, U.S. Dept Commerce, NOAA-TM-NMFS-SWFSC Technical Memorandum. La Jolla, CA. 199 pp.

Condit, R.S., and B.J. LeBoeuf. 1984. Feeding habits and feeding grounds of the northern elephant seal. J. of Mam., Vol. 65, pp. 281-290.

Croll, D.A., Tershy, B.R., Hewitt, R., Demer,D., Hayes, S., Fiedler, PI, Popp, J., and Lopez, V.L. 1998. An integrated approach to the foraging ecology of marine birds and mammals., Deep-Sea Research II, Vol. 45, pp. 1353-1371.

Darling, J.D., K.E. Keogh, T.E. Steeves. 1998. Gray whale (*Eschrichtius robustus*) habitat utilization and prey species off Vancouver Island, B.C. J. Marine Mammal Science, Vol. 14(4), pp. 692-720.

DeLong, R.L., and G.A. Antonelis. 1991. Impacts of the 1982-1983 El Niño on the northern fur seal population at at San Miguel Island, California. Pinnipeds and El Niño: Responses to Environmental Stress. (Trillmich, F., and K. Ono, Eds.) Springer-Verlag, New York. Pp. 75-83.

DeLong, R.L., S.R. Melin. 1999. Population monitoring studies of northern fur seals at San Miguel Island, California. Fur seal investigations, 1997. (E.H. Sinclair, BW Robson, Eds) US Dep. Commer. NOAA Tech. Memo NMFS-AFSC-69 Kodiak, AK. Pp. 73-80.

Dohl, T.P., R.C. Guess, M. Duman and R.C. Helm. 1983. Cetaceans of central and northern California: status, abundance, and distribution Final Rep, Minerals management Service Contract 14-12-0001-29090 OCS Study MMS 84-0044. Los Angeles, CA. 143 pp.

Dohl, T.P., R.C. Guess, M.L. Duman, and R.C. Helm. 1983. Cetaceans of Central and Northern California, 1980-1983: Status, Abundance, and Distribution. Part of Investigator's Final Report, Marine Mammal and Seabird Study, Central and Northern California, Contract No.14-12-0001-29090. Prepared by Center for Marine Sciences, University of California, Santa Cruz, for the Pacific OCS Region, Minerals Management Service. OCS Study MMS 84-0045. Santa Cruz, CA. 284 pp.

Estes, J.A., B.B. Hatfield, K. Ralls, J. Ames. 2003. Causes of mortality in California sea otters during periods of population growth and decline. J. Marine Mammal Science, Vol. 19(1), pp. 198-216.

Forney, K.A., J. Barlow, J.V. Carretta. 1995. The abundance of cetaceans in California waters. Part II: Aerial surveys in winter and spring of 1991 and 1992. Fish Bull. Vol. 93, pp. 15-26.

Forney, K.A., J. Barlow, and J.V. Carretta. 1995. The abundance of cetaceans in California waters. Part I: Aerial surveys in winter and spring of 1991 and 1992. Fish. Bull., Vol. 93, pp. 15-26.

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

Forney, K.A. and J. Barlow. 1998. Seasonal patterns in the abundance and distribution of California cetaceans, 1991-1992. Mar. Mam. Sci., Vol. 14, pp. 460-489.

Forney, K.A. 1999a. The abundance of California harbor porpoise estimated from 1993-97 aerial line-transect surveys. NOAA/SWFSC Admin.Rep. LJ-9-02. La Jolla, CA. 16 pp.

Forney K.A. 1999b. Trends in harbor porpoise abundance off central California, 1986-95: Evidence for interannual changes in distribution? J. Cetacean Res. Manage., Vol. 1, pp. 73-80.

Forney, K.A., and M.M. Muto, and J. Baker. 2000. Draft U.S. Pacific marine mammal stock assessments: 1999. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-SWFSC-282. La Jolla, CA. 62 pp.

Gaskin, D.E. 1984. The harbour porpoise (*Phocoena phocoena*): regional populations, status, and information on direct and indirect catches. Rep. Int. Whal. Comm., Vol. 34, pp. 569-586.

Glantz, M.R., and J.D. Thompson. 1981. Resource Management and Environmental Uncertainty. Wiley, New York. 63 pp.

Green, G.A., J.J. Brueggeman, R.A. Grotefendt, D.E. Bowlby, M.L. Bonnell and K.C. Balcomb, III. 1992. Cetacean distribution and abundance off Oregon and Washington, 1989-1990. Oregon and Washington Marine Mammal and Seabird Surveys. (J.J. Brueggeman, Ed.). Minerals Management Service Contract Report 14-12-0001-30426. Anchorage, AK. 121 pp.

Gulland, F.M.D., H. Perez-Cortes, J. Urban R., L. Rojas-Bracho, G. Ylitalo, C. Kreuder, and T. Rowles. 2002. Eastern north Pacific gray whale (*Eschrichtius robustus*) unusual mortality event, 1999-2000: A compilation. International Whaling Commission Rpt SC/54/BRG23. Cambridge, UK. 200 pp.

Harris, M. Unpublished data. Survey data of southern sea otters in California: Fall 2001 and Spring 2002 counts. Marine Region, California Department of Fish and Game. San Diego, California.

Harvey, J.T., R.C. Helm, and G.V. Morejohn. 1995. Food Habits of Harbor Seals Inhabiting Elkhorn Slough, California. California Fish and Game, Vol. 81, pp. 1-9.

Hastings, K.K. and W.J. Sydeman. 2002. Population status, seasonal variation in abundance, and long-term population trends of Steller sea lions (*Eumetopias jubatus*) at the South Farallon Islands, California. Fish. Bulletin, Vol. 100, pp. 51-62.

Kajimura, H. 1980. Distribution and migration of northern fur seals (*Callorhinus ursinus*) in the Eastern Pacific. Further analysis of pelagic fur seal data collected by the United States and Canada during 1958-74. Kajimura, H. R.A. Lander, M.A. Perez, A.E. Yor (eds). North Pacific Fur Seal Commission 23rd annual meeting Standing Scientific Committee 7-12, April 1980, USSR: Moscow. pp. 19-48.

Kajimura, H. 1984. Opportunistic feeding of the northern fur seal, *Callorhinus ursinus*, in the eastern North Pacific Ocean and eastern Bering Sea. U.S. Dept. of Commerce, NOAA Technical Report NMFS SSFR-779. Washington, D.C. 79 pp.

Keiper, C.A. 2001. Marine mammals off central California relative to hydrography; 1986-94, 1997-99. MS Thesis, Moss Landing Marine Laboratories, San Jose State University, 98 pp.

Keiper, C.A., D.G. Ainley, S.G. Allen, J.T. Harvey. *In Review*. Inter-annual variability in ocean climate and marine mammal occurrence patterns off central California, 1986-1994, 1997-1999. Marine Ecology Progress Series.

Kenyon, K.W. and F. Wilke. 1953. Migration of the northern fur seal, *Callorhinus ursinus*. J. of Mamm., Vol. 34(1), pp. 86-98.

Kieckhefer, T.R. 1994. Feeding ecology of humpback whales in continental shelf waters near Cordell Bank, California. MS thesis, Moss Landing Marine Laboratories, San Jose State University, San Jose, CA. 170 pp.

Koski, W.R., J.W. Lawson, D.H. Thomson, W.J. Richardson. 1998. Point Mugu sea range marine mammal technical report. Naval Air Warfare Center Weapons Division. San Diego, CA. 280 pp.

Leatherwood, S., and R.R. Reeves. 1983. The Sierra Club Handbook of Whales and Dolphins. Sierra Club, San Francisco, CA. 302 pp.

Le Boeuf, B.J., D. Crocker, S. Blackwell, P. Morris. 1993. Sex differences in diving and foraging behaviour of northern elephant seals. Marine Mammal: Advances in Behavioural and Population Biology. (I. Boyd, ed.). Oxford Univ. Press. pp. 23-45.

LeBoeuf, B.J., K. Ono and J. Reiter. 1991. History of the Steller sea lion population at Año Nuevo Island, 1961-1991. National Marine Fisheries Service, Southwest Fisheries Science Center, Administrative Report LJ-91-45C. La Jolla, CA. pp. 24.

Lowry, Mark S. Unpublished data. Survey data for haulouts and rookeries of California sea lion (*Zalophus californianus*) and Steller sea lion (*Eumetopias jubatus*) in central and northern California, 1998-2001. National Marine Fisheries Service, Southwest Fisheries Science Center. La Jolla, CA.

Lowry, M.S., C.W. Oliver, C. Macky, and J.B. Wexler. 1990. Food habits of California sea lions *Zalophus californianus* at San Clemente Island, California, 1981-1986. Fish. Bull. U.S., Vol. 88, pp. 509-521.

Lowry, M.S., B.S. Stewart, C.B. Hyeath, P.K. Yochem, and J.M. Francis. 1991. Seasonal and annual variability in the diet of California sea lions *Zalophus californianus* at San Nicolas Island, California, 1981-1986. Fish. Bull. U.S., Vol. 89, pp. 331-336.

Lowry, Mark S. and J. V. Carretta (In review). Pacific harbor seal, *Phoca vitulina richardsi*, census in California during May-July 2002. To be published as: NOAA Technical Memorandum NMFS, NOAA-TM-NMFS-SWFSC. La Jolla, CA.

Lowry, M.S. and K.A. Forney. In Review. Abundance and distribution of California sea lions in central and northern California during 1998 and summer 1999. Fish. Bull. US.

MMS (Minerals Management Service). 2001. Marine Mammal and Seabird Computer Database Analysis System for Washington, Oregon and California, 1975-1997 (MMS-CDAS, version 2.1). Prepared by Ecological Consulting, Inc. (now R.G. Ford and Consulting Co.), Portland, Oregon for the Minerals Management Service, Pacific OCS Region, Order No.1435-01-97-PO-4206. Anchorage, AK.

Mate, B.R., B.A. Lagerquist, and J. Calambokidis. 1999. Movements of North Pacific blue whales during their feeding season off Southern California and their southern fall migration. Mar. Mamm. Sci., Vol. 15 (4), pp. 1246-1257.

Melin, S.R., and R.L. Delong 2000. Population and monitoring studies of northern fur seals at San Miguel Island, California. Fur seal investigations, 1998. B.W. Robson (ed.). NOAA Tech. Memo. NMFS-AFSC-113. Silver Spring, MD. pp. 41-5.

Morejohn, G.V. 1979. The Natural History of Dall's Porpoise in the North Pacific Ocean. Behavior of Marine Animals, Vol. 3. Cetaceans. H.E. Winn, and B.L. Olla, eds. Plenum, New York, NY. pp. 45-83.

Miller, M.A., L.A. Gardner, C. Krueger, D.M. Paradies, K.R. Worcester, D.A. Jessup, E. Dodd, M.D. Harris, J.A. Ames, A.E. Packham and P.A. Conrad. 2002. Coastal freshwater runoff is a risk factor for *Toxoplasma gondii* infection of southern sea otters (*Enhydra lutris nereis*). Intl. J. of Parasitology, Vol. 32, pp. 997-1006.

National Marine Fisheries Service. 1992. Final recovery plan for Steller sea lions, *Eumetopias jubatus*. Prepared by the Steller sea lion recovery team for the National Marine Fisheries Service. Silver Spring, Maryland. 290 pp.

National Marine Fisheries Service. 2000. Biological opinion on the California/Oregon Drift Gillnet Fishery. Silver Spring, MD. 64 pp.

Nusbaum, J. 2002. Population size and breeding success of the Northern elephant seal on Southeast Farallon Island, PRBO Marine Science Division; Report to USFWS, San Francisco Bay National Wildlife Refuge. San Francisco, CA. 59 pp.

Oliver, G.W., J. Gilardi, C. Toropoa, P. Folkens, K. Cronin, N. Bodorff, K. Sanchez, W. Damon, K.A. Zagzebski, B. Winning. 2001. Gray whales in San Francisco Bay. Poster Abstract submitted at the 14th Biennial Conference on the Biology of Marine Mammals.

Orr, R.T. 1966. Risso's Dolphin on the Pacific Coast of North America. J. of Mamm., Vol. 47, pp. 341-343.

Perryman, W.L., M.A. Dohahue, P.C. Perkins, S.B. Reilly. 2002. Gray whale calf production 1994-2000: Are observed fluctuations related to changes in seasonal ice cover? J. Mar. Mam. Sci., Vol. 18(1), pp. 121-144.

Pettee, J. 1989. Female northern elephant seal reproductive success at Point Reyes National Seashore and micro-habitat features. MS Thesis, San Francisco State University, San Francisco, CA.

Pyle, P. and L. Gilbert. 1996. Occurrence patterns and trends of cetaceans recorded from southeast Farallon Island, California, 1973 to 1994. Northwestern Naturalist 77:1-8.

Pyle P., D.L. Long, J. Schonewald. 2001. Historical and recent colonization of the South Farallon Islands, California, by Northern fur seals (*Callorhinus ursinus*). J. Mar. Mam. Sci., Vol. 17(2), pp. 397-402.

Section 2.3: BIOGEOGRAPHY OF MARINE MAMMALS

Ream, R.R., J.D. Baker and R.G. Towell. 1999. Bogoslof Island studies, 1998. Fur seal investigations, 1997. E.H. Sinclair and B.W. Robson (eds). US Dep Commer, NOAA Tech Memo NMFS-AFSC-69. Kodiak, Ak. 268 pp.

Reidman, M.L. and J.A. Estes. 1990. The sea otter (*Enhydra lutris*): Behavior, ecology, and natural history. USFWS. Biological Report, Vol. 90(14).

Rugh, D.J., J.M. Breiwick, R.C. Hobbs, and J.A. Lerczak. 2002. A preliminary estimate of abundance of the eastern North Pacific stock of gray whales in 2001 and 2002. Paper SC/545/BRG6 presented to the IWC Scientific Committee, April 2002. 14 pp.

Schoenherr J.R. 1991. Blue whales feeding on high concentrations of euphausiids around Monterey Submarine Canyon. Can. J. Zool., Vol. 69, pp. 583-594.

Stewart, B.S. and H.R. Huber. 1993. *Mirounga angustirostris*. Mammalian Species 449:1-10.

Stewart, B.S., B.J. Le Boeuf, P.K. Yochem, H.R. Huber, R.L. DeLong, R.J. Jameson, W. Sydeman, and S.G. Allen. 1994. History and present status of the northern elephant seal population. Elephant Seals. B.J. Le Boeuf and R. M. Laws (eds.) Univ. Calif. Press, Los Angeles. pp. 101-135.

Stroud, R.K., C.H. Fiscus, and H. Kajimura. 1981. Food of the Pacific White-sided Dolphin, *Lagenorhynchus obliquidens*, Dall's Porpoise, *Phocoenoides dalli*, and Northern Fur Seal, *Callorhinus ursinus*, off California and Washington. Fishery Bulletin, Vol. 78, pp. 951-959.

Sydeman, W.J., S.G. Allen. 1999. Pinniped population dynamics in central California: Correlations with sea surface temperature and upwelling indices. Mar. Mam. Sci., Vol. 15(2), pp. 446-461.

Trillmich F. and K.A. Ono (eds). 1991. Pinnipeds and El Niño: Responses to environmental stress. Springer-Verlag, Berlin. 97 pp.

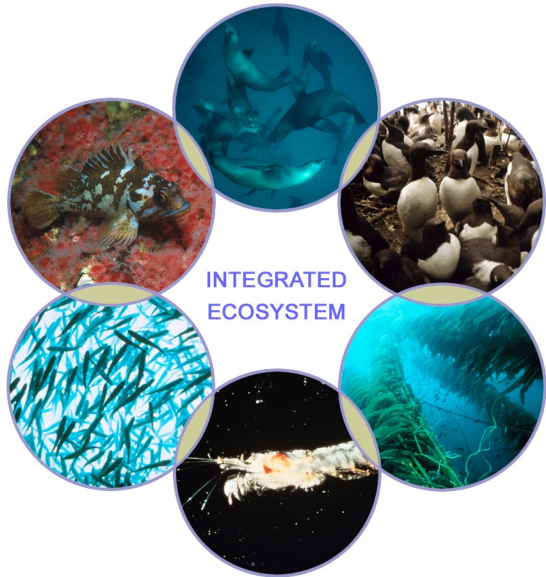
U.S. Geological Survey 2002. (www.werc.usgs.gov/otters/ca-surveydata.html).

USFWS. 2000. Draft Revised Recovery Plan for the Southern sea otter (*Enhydra lutris nereis*). Portland, Oregon. U.S. Fish and Wildlife Service, Ecological Services, Ventura Field Office. Ventura, California. 64 pp.

Weise, M.J. 2000. Abundance, food habits, and annual fish consumption of California sea lion (*Zalophus californianus*) and its impact on salmonid fisheries in Monterey Bay, CA M.S. Thesis, Moss Landing Marine Laboratories, San Jose State University. 87 pp.

Weise, M.J., J.T. Harvey 2001. Nighttime foraging of harbor seals on winter-run steelhead in the San Lorenzo River, California. Paper presented at the 14th Biennial Conference on the Biology of Marine Mammals. 27 pp.

Section 3: INTEGRATION OF ANALYSES



INTRODUCTION

The greatest challenge in developing a large-scale biogeographic assessment is the synthesis and subsequent analysis of spatial data collected at different scales for varied objectives (Gotway and Young 2002). This is particularly true when attempting to describe meso-scale (tens to hundreds of kilometers) spatial patterns using data for a range of taxa that were each collected using different sampling techniques. The taxon-specific sections of this document describe spatial patterns of community structure for marine birds, mammals, and fishes. The intent of this section is to coalesce these results and construct a unified and biologically relevant assessment of the biogeographic patterns observed.

There are a number of ways to address the challenge of integrating results for multiple taxa, and this section contains results for three (of many) reasonable options. This integration effort has been tailored to the NMSP mission of “...enhancing biodiversity, ecological integrity, and cultural heritage”, and specifically focuses on the notion of biodiversity in describing the overall biogeography of the region.

After a thorough assessment of the spatial data for each taxon, it was concluded that the marine mammal data were not robust enough in present form to include in the integration process. As such, only birds and fish were considered here. Additional efforts to reconcile outstanding issues in the marine mammal data are ongoing. A final integrated analysis, including mammal data, will be completed during Phase II of this assessment. The integration alternatives provided in this section include:

- Option 1: A co-occurrence analysis of diversity hot spots for marine birds and marine fishes

- Option 2: A co-occurrence analysis of marine bird density and fish density
- Option 3: A co-occurrence analysis of density and diversity (options 1 and 2 combined) for both fish and marine birds

In the first of these approaches, only patterns of species diversity were analyzed. This index was relatively simple to calculate using the data available for birds and fishes, and represents a common metric for integration. The second option focuses on spatial patterns of density. Density is a more intuitive measure than diversity, and it highlights regions of highest marine bird concentrations (abundance). An added attraction of density is that it is only weakly influenced by effort. The third approach incorporates the two metrics for marine birds and fishes simultaneously by combining results of options 1 and 2.

Metrics used in these three options were chosen to best define the biogeography for each taxon based on the available data. Once each integration parameter was mapped, patterns of community structure were superimposed and interpreted in the context of various biological and physical covariates. These spatial covariates were used to better understand general biogeographic patterns, and through interpretation, suggest reasons for the observed spatial trends. For example, results indicated that a portion of highest observed bird and fish diversity occurred adjacent to the shelf/slope interface. It is well documented that strong upwelling of deep ocean waters consistently occurs in areas along the slope. Nutrients in these waters support high phytoplankton productivity, which stimulates a cascade of productivity at all levels of the marine food web (Bolin and Abbott, 1963; Ryther, 1969; Malone, 1971; Barber and Chavez, 1983; Chavez 1995, 1996; Bakun, 1996).

Furthermore, by combining multiple parameters across taxa (option 3), it was possible to link results presented in earlier sections to an integrated composite. This approach provides a clear and tractable interpretation that the reader can follow as a logical end point to the preceding series of analyses. The combination of diversity and density presents an inclusive view of important areas across taxa, and is less likely to overlook regions of potential importance when compared to maps depicting a single estimate (e.g., options 1 and 2). This is a critical point as the most diverse patch in a seascape is not necessarily the most productive. In addition to the general patterns observed for each metric, the spatial coincidence of hot spots among taxa is emphasized to provide a view into the integrated ecosystem. The metrics used in this section are similar to those described in sections 2.1 (fish) and 2.2 (marine birds); however, data were interpolated to produce

a continuous modeled surface rather than estimates per 5 minute grid. This approach takes into consideration the spatial structure in the data to model the gradient of the metric between any given pair of sampling points. This results in smoothed surfaces that permit easier visualization of biologically significant areas. Resulting large-scale patterns have been described in the context of sanctuary boundaries to provide insights that may enhance management efficacy in these protected areas.

DATA AND ANALYSES

Integration Metrics. There are a number of ways by which ecologists measure diversity. The simplest metric is a count of the total number of unique species in a community, also called species richness (S). This is a straightforward, though potentially misleading, measure of diversity. Sampling must be conducted at all locations with the same amount of effort for this estimate to be comparable across a study region or between data sets. Unfortunately, this was not the case with any of the source data available for integration. For example, marine bird observation transects were far more numerous (more effort) near shore, and declined dramatically with distance from shore. Because this is often the case with biological sampling, a number of diversity indexes have been developed that are, in theory, more independent of sample size. These are based on the relationship between species richness and the total number of individuals observed (n), both of which increase as a function of effort, and, ideally, cancel out the effect of effort on the resulting index (Ludwig and Reynolds, 1988). Here the Shannon index of diversity (Shannon and Weaver, 1949) was chosen, as this index is the most widely used in community ecology and has relatively small statistical bias when sample sizes are large (as is the case with this source data).

Diversity may be thought of as being composed of two distinct components: 1) species richness, and 2) species evenness. Evenness is defined as how the number of individuals is distributed among the species. For example, for a community comprised of five species with 70% of the individuals belonging to one species and 30% distributed among the remaining four species, the evenness component would be lower than if there were a more even distribution of individuals among the five species (Ludwig and Reynolds, 1988) (Figure 79). Maximum diversity for a given number of species and individuals is achieved where equal numbers are found for each species in a community. For consistency, data for all taxa included in this section were summarized by five minute grids (see sections 2.1, 2.2, 2.3). Total diversity was estimated within each grid cell using the Shannon index (H');

$$H' = - \sum_{i=1}^S \left[\left(\frac{n_i}{n} \right) \ln \left(\frac{n_i}{n} \right) \right]$$

where n_i is the number of individuals belonging to the species (S) in the sample (5 minute grid), and n is the total number of individuals in the sample (Ludwig and Reynolds 1988). Diversity was calculated independently for birds and fishes using all species observed within a grid cell.

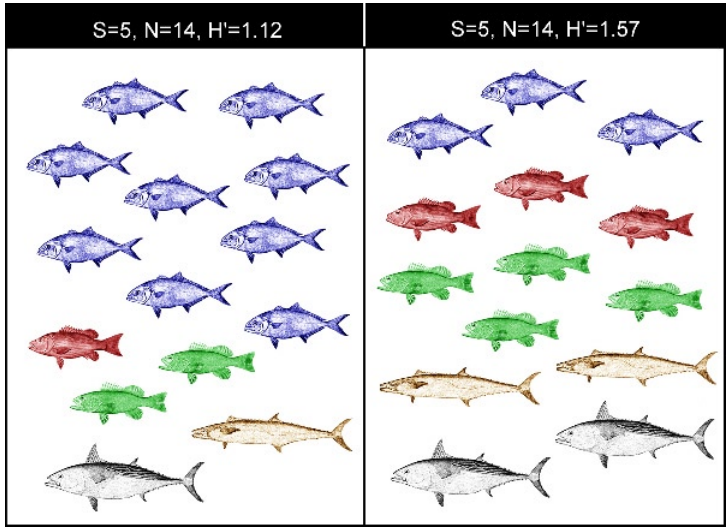


Figure 79. Pictogram of species diversity. Both fish communities are comprised of 5 species and 14 individuals. In the community on the left side, there are 9 individuals of species 1, 1 of species 2, 2 of species 3, 1 of species 4, and 1 of species 5. Using the distribution of abundance within this community, Shannon’s Index of diversity is 1.12. The community on the right also consists of 5 species with 14 individuals; however, the distribution of abundance is more even (2, 3, 3, 4, and 2 individuals), and consequently Shannon’s Index is higher (1.57).

Once diversity was calculated for each taxon in each sample, a continuous map surface was interpolated to predict diversity patterns throughout the study area. The same process was used to model density (see below for detailed methods).

Spatial Modeling. This section details the procedure used to process input data for the integration analyses. While technical in nature, it provides the information necessary for NMSP and others to generate results identical to those presented here using data provided in the appendix to this document (CD-ROM), and to explore results of alternate modeling options. The observed patterns in diversity and density were found to be robust to changes in model parameters; however, calculations of the aerial extent of persistent patterns may be more sensitive. For example, the location of areas of high bird diversity tends to be relatively constant, regardless of model parameters. The quantity (e.g., square kilometers) of these high areas that fall inside sanctuary boundaries, however, may change.

Section 3: INTEGRATION OF ANALYSES

For interpolation and calculation of spatial autocorrelation statistics, data for each 5 minute grid cell were assigned to the cell centroid. All data were analyzed in the Universal Transverse Mercator (UTM) projection. Projection is necessary to ensure that the value of x and y units is equivalent and constant across the study region. The spatial modeling process to generate an interpolated surface consisted of the following sequence of operations:

1) Checking for Spatial Autocorrelation: Prior to interpolation, all data were tested for the presence of spatial autocorrelation. Positive autocorrelation (where values for neighboring pairs of points are more similar to one another than are distant ones) is important for accurate interpolation. Moran's I and Geary's C statistics were calculated for each interpolated variable to test for the presence of significant spatial autocorrelation using CrimeStat (Levine, 2002). Moran's I is the standard autocorrelation statistic and provides a global (i.e. across the study area) test of spatial autocorrelation. Geary's C is more sensitive to autocorrelation within small neighborhoods. Confirmation of statistically significant spatial autocorrelation suggests that point data are suitable for interpolation. As such, interpolation was performed only where this was true for both autocorrelation statistics.

2) Detrending: Detrending is done to 'standardize' the estimate across the analysis extent, and is a prerequisite for the interpolation procedure used here. After interpolation, the removed trend is added back into the model results. Each interpolated variable was plotted against Northing and Easting, and a linear trend was fit to each plot. When significant trend ($p < 0.05$) was present for either Northing or Easting, the data were detrended (first order) before variogram modeling and kriging.

3) Variogram Modeling: Empirical variograms show the decrease in relatedness between pairs of points as a function of distance. In order to calculate the empirical variogram, pairs of points must be binned by distance, and an average value (diversity, density) calculated for all pairs within a given bin. The size of the bin is referred to as the lag size. A variogram model is fit to the empirical variogram and its parameters are later used in interpolation. Empirical variograms were calculated using the default lag size and number, as well as for 1km, 5km, and 10km lag sizes. The appropriate lag size and number of lags were chosen to optimize variogram coherence. Directional variograms were then plotted to investigate possible anisotropy not removed by detrending. Strong anisotropy was found only for the fish density data, and accordingly a geometrically anisotropic variogram model was fit to this data set. Spherical variogram models were fit to the empirical variograms. A spherical model was chosen based

on the pattern of the empirical variograms and the lack of data at short lag distances (due to the five minute minimum separation between points), which are necessary to differentiate between spherical and Gaussian models.

4) Surface Interpolation: The interpolation method used is termed 'ordinary kriging'. Kriging is a linear interpolation method that allows predictions of unknown values of a random function from observations at known locations (Kaluzny et al., 1998). Ordinary kriging is the kriging method generally used for interpolation of a single continuous variable of unknown mean. Kriging is preferred over other interpolation methods because: 1) weights are based on an empirical assessment of the data's spatial structure (the variogram), 2) kriging is an unbiased predictor, and 3) for many variables, kriging has been shown to outperform other interpolation methods, such as inverse distance weighting (IDW) and triangulated irregular networking (TIN) (Guan et al., 1999). Before kriging can be applied, two assumptions must be checked. The first is stationarity; the mean (and ideally the variance) must be constant across the spatial extent of the data. That is, any large scale trend must be removed (see #2 above). The second assumption is isotropy of the variogram. The covariance between any two points is assumed to be a function only of the distance between the points, not of their location or angle. This assumption can be examined and, if necessary, corrected for during the variogram modeling stage (see #3 above). Trend analysis was conducted using JMP statistical software (SAS Institute), while detrending, variogram modeling, and kriging were conducted using the ArcView (GIS) Geostatistical Analyst Extension (ESRI Inc.).

The kriging neighborhood was set to the twenty nearest neighbors with a minimum of five neighbors for each 90 degree angular sector for the fish data, and reduced to eight and five for birds in order to capture small scale variability. Cross validation was conducted to assess model accuracy by regressing observed versus predicted values. Maps of the kriging standard error were also generated and used to restrict the analysis extent. In order to avoid unsupported extrapolation into poorly sampled areas, the interpolated maps were clipped to remove areas of higher standard error. Interpolated maps were clipped so that only grid cells for which the standard error was in the lowest 20% were used for subsequent display and analysis.

5) Correcting for Effort: Total effort was calculated as the total length of trawls falling within a grid cell for the NMFS trawl data and as the total area surveyed within a grid cell for the marine bird survey data. Although diversity is less related to effort than other metrics, some significant correlation ($p < 0.05$) between the two was found for both fish and birds. When such

Table 26. Summary statistics and parameter estimates for spatial models.

	Sample Size	Moran's I	Geary's C	Detrending?	Lag size (km)	Number of lags	Range (km) (minor range for anisotropic model)	Nugget	Partial Sill	Cross-validation r^2	Neighbors (total, minimum per sector)
Bird diversity	1,163	0.141**	0.830**	Yes	20.451	12	99.851	0.25	0.117	0.541	8,2
Bird diversity residual	1,163	0.067**	0.893**	Yes	9.966	12	88.062	0.199	0.125	0.407	8,2
Bird density	1,403	0.058**	0.891**	Yes	5	30	149.54	1,189.30	1,189.50	0.253	20,5
Fish diversity	301	0.018**	0.973*	No	5	20	29.595	0.148	0.046	0.025	20,5
Fish diversity residual	301	0.013*	0.975*	No	5	10	18.394	0.11	0.061	0.076	20,5
Fish density	301	0.020**	0.969*	No	5	8	37.929 (16.802)	0.0046	0.001	0.074	20,5

** indicates significance at $p = 0.001$, * indicates significance at $p = 0.05$

a correlation exists, maps of diversity may simply reflect the distribution of effort. In order to correct for differences in effort across the study region, the following technique was applied: A second order polynomial regression of diversity on effort was conducted and the residuals were interpolated as described above. The interpolated map of residuals depicts areas of higher or lower diversity relative to that expected given the amount of local effort. This map was overlaid on the interpolated map of diversity to visualize the impact of effort on the observed patterns in diversity. Although significantly correlated with effort, fish diversity showed nearly identical patterns as the map of fish diversity residuals. Fish diversity is therefore not shown with the overlay of residuals. Patterns of marine bird diversity, however, differed substantially from patterns of the bird diversity residuals, indicating that differences in effort are responsible for some of the observed pattern. Marine bird diversity hot spots, as represented by the top 20% of diversity cell values, are therefore presented, along with an overlay of the lower third of the diversity residuals for marine

birds. Areas of high marine bird diversity that overlap with low residuals should be interpreted with caution, as these hot spots may simply reflect areas of unusually high effort. Since bird and fish density were only weakly correlated with effort, no attempt was made to correct the density maps.

ANALYTICAL MAP PRODUCTS

Spatial Statistics. Table 26 summarizes the results of spatial autocorrelation tests, variogram fitting, and kriging cross validation. All variables were found to be significantly positively spatially autocorrelated ($p < 0.05$) by both the Moran's I and Geary's C statistics, for fish and marine birds. Spatial autocorrelation was more pronounced in the marine bird data than in the fish data resulting in better model fit and a higher cross-validation r-squared value for the bird data sets.



Gulf of the Farallones National Marine Sanctuary



Gulf of the Farallons National Marine Sanctuary

Section 3: INTEGRATION OF ANALYSES

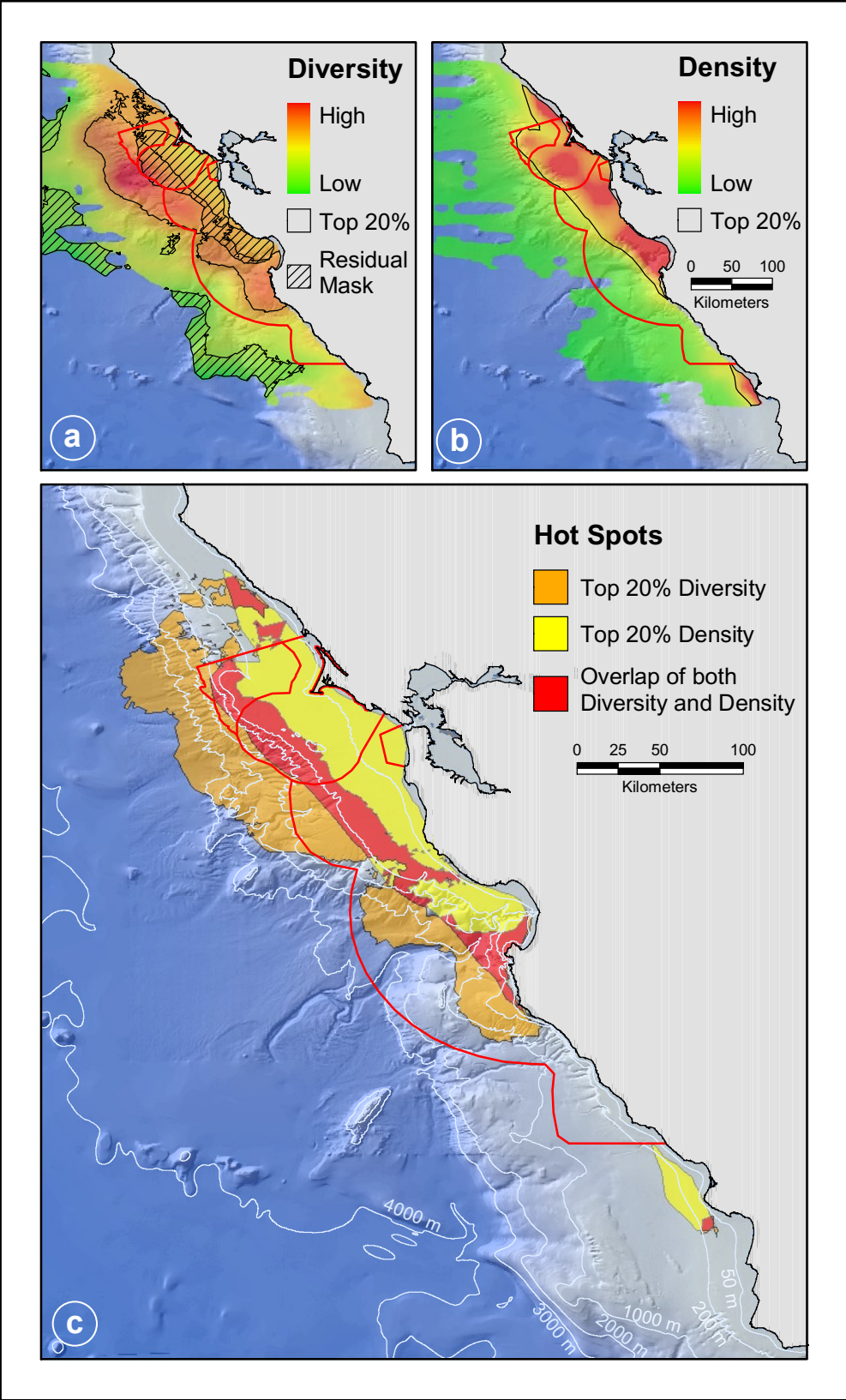


Figure 80. Estimated diversity (a), density (b), and hot spots (top 20%) (c) for marine birds.

ABOUT THESE MAPS
Figure 80a depicts interpolated marine bird diversity throughout the study region. The top 20% of predicted diversity is bounded by a thin black line. Because bird diversity was significantly correlated with survey effort, we have also provided a mask (cross hatched area) indicating where residual estimates provided evidence that diversity was lower than expected given the amount of effort spent there (residuals were among the lowest third). Interpret with caution in this area, as the expression of high diversity under the mask may actually be an artifact of high sampling effort. Figure 80b depicts interpolated bird density. Again, the top 20% of this estimate is bounded by a thin black line. No statistical relationship was found between density and effort; therefore, no residual mask is provided for this model. Figures 80a and b have both been clipped using the standard error estimate for the interpolated surfaces (access these data on the CD-ROM). This was done to avoid unsupported extrapolation into poorly sampled areas. Figure 80c depicts the top 20th percentile for diversity and density and the overlap between them.

DATA SOURCES
R.G. Ford and J.L. Casey. 2003. CDAS Density Maps for Marine Birds off North/Central California, developed for NOAA's National Centers for Coastal Ocean Science. Portland, Oregon.

METHODS
See "Data and Analysis" section.

RESULTS AND DISCUSSION
Species Diversity. The interpolated maps of marine bird diversity show one continuous area of high diversity along the continental slope, and, to a lesser extent, along the shelf between Point Arena and Point Sur. Within this area, diversity appears highest on, and seaward of, the Farallon Escarpment in the northwestern corner of the Monterey Bay NMS (Pioneer Canyon), and off of the region between Point Lobos and Point Sur (refer to locator map). Since marine bird diversity was correlated with survey effort, much of the hot spot region coincides with areas of high survey effort. The Farallon Escarpment, in particular, received a disproportionate amount of survey effort. When the map of interpolated residuals was overlaid on marine bird diversity, some parts of the diversity hot spot (top 20%) fell in a region of low (bottom third) residual diversity (the masked portion of Figure 79a). This indicates that the high estimated diversity in the Farallon Escarpment is due, at least in part, to high sampling effort. The portion of the marine bird diversity hot spot between Point Lobos and Point Sur coincides with a region of high residual diversity. This indicates that diversity in this region was both high and higher than expected given relatively moderate sampling effort.

Overall, a total of 62,000 square kilometers were modeled for bird diversity. Of that, roughly 12,000 square kilometers were classified as a hot spot (top 20% of estimated diversity). Approximately 28% of the entire modeled surface, and 58% (7,158 km²) of the hot spot, fell inside the boundaries of the three National Marine Sanctuaries. This disproportionate allocation of high diversity inside sanctuaries indicates that current boundaries generally incorporate areas of high regional diversity. A considerable area of high diversity can be found seaward of the northern Monterey Bay NMS, and seaward of the entire Gulf of the Farallones and Cordell Bank NMS boundaries. As mentioned in section 2.2, the persistence of high species diversity along the shelf break may be attributed to this natural physiographic

feature acting as a biogeographic boundary, where oceanic and shelf species of birds show maximum overlap. The region seaward of the Farallon Islands displays high diversity not only because of its proximity to the shelf break, but also because many species of birds breed on these islands and would not otherwise be found so far offshore.

Density. A large region of high (top 20th percentile) marine bird density exists adjacent to and shoreward of the marine bird diversity hot spot. This density hot spot covers most of the shelf waters of all three sanctuaries, from Point Sur in the south to midway between Bodega Head and Point Arena in the north. The density hot spot extends into Monterey Bay. Major regions of overlap between marine bird diversity and density occur along the shelf break. An additional density hot spot exists off of Morro Bay to the south of the Monterey Bay NMS. There is some indication of high marine bird diversity in this region as well.

A total of 60,000 square kilometers were modeled for bird density, with approximately 10,000 square kilometers classified in this analysis as a hot spot. Approximately 28% of the entire modeled surface fell inside the boundaries of the three National Marine Sanctuaries; however, 84% (8,962 km²) of the high marine bird density hot spot was found in the sanctuaries. The proportion of high density inside sanctuaries suggests that the boundaries include most areas of high density.

Summary. Patterns of bird diversity and density exhibited distinct spatial patterns, with diversity concentrated from the slope seaward, and density from the slope shoreward. The overlap of these estimates mainly occurs along the shelf break; an area of high meso-scale bathymetric complexity. It is interesting to note that marine bird diversity exhibited a statistically significant positive correlation ($r=0.33$, $p<0.0001$) with bathymetric variance (Figure 81a)(see section 2.1.1 for details on this estimate). Density, on the other hand, exhibited a strong negative correlation ($r=0.65$, $p<0.0001$) with depth rather than bathymetric variance (Figure 81b).

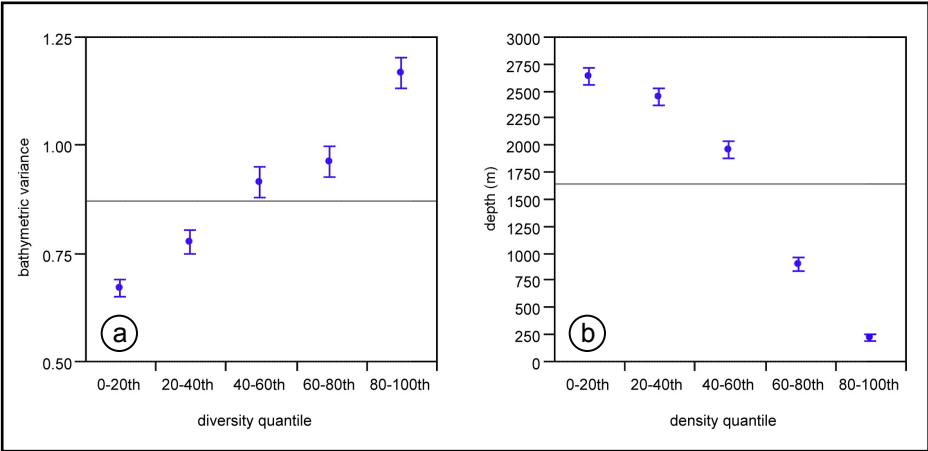


Figure 81. The left graphic (a) shows the strong positive relationship observed between bird diversity and bathymetric variance, while the right graphic (b) shows a strong negative relationship between bird density and depth. In both cases, the estimate (diversity and density) have been classified into 20th percentiles.

Section 3: INTEGRATION OF ANALYSES

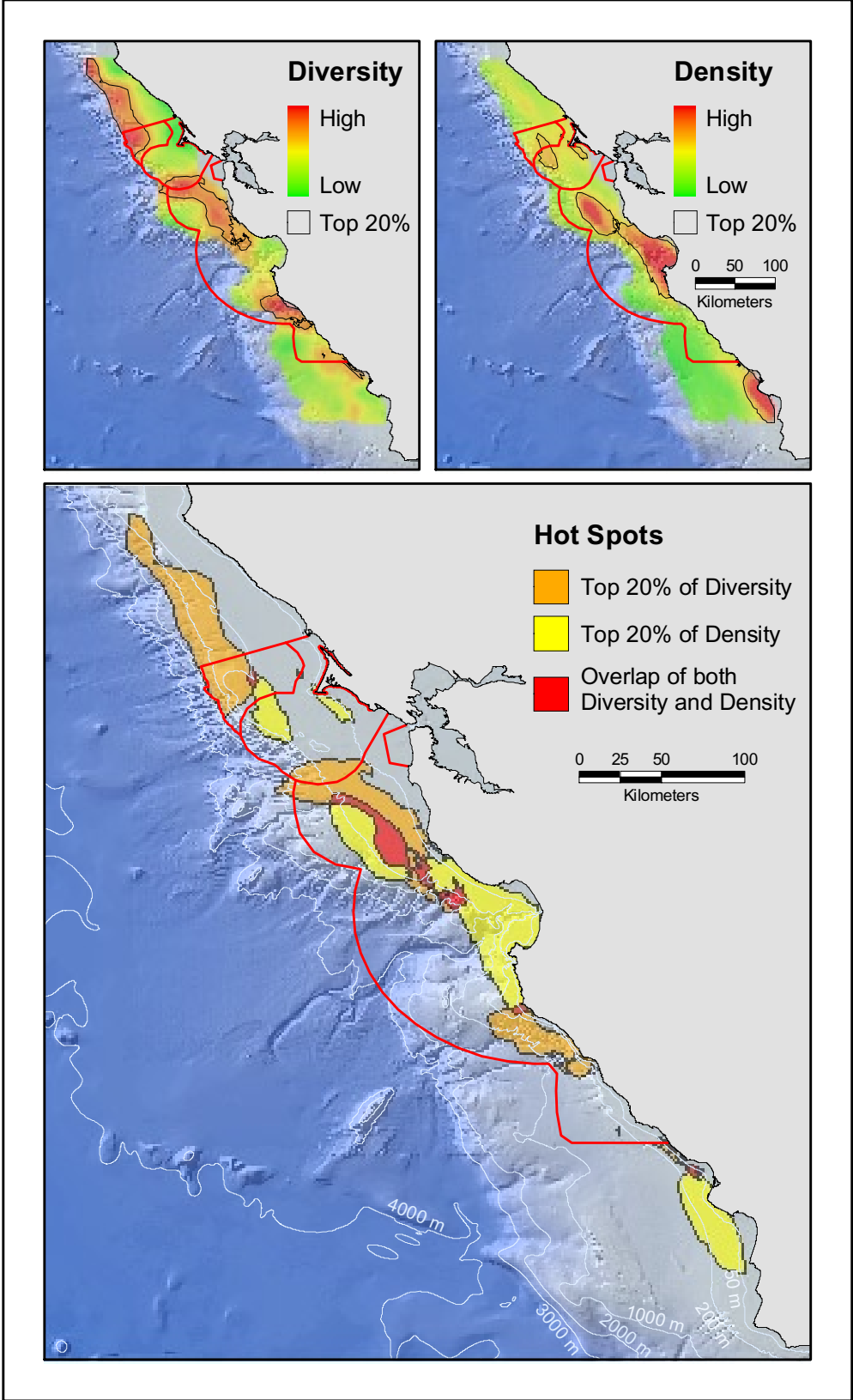


Figure 82. Estimated diversity (a), density (b), and hot spots (top 20%) (c) for fish.

ABOUT THESE MAPS

Figure 82a depicts estimated demersal fish diversity throughout the study region. Unlike the mean diversity mapped in section 2.1.1, this surface was generated using estimates of total diversity for each 5 minute grid cell. The top 20% of predicted diversity is bounded by a thin black line. Though fish diversity was significantly correlated with survey effort in this model, high residual values overlapped areas of highest (top 20%) estimated diversity. This indicates that interpolated areas of highest diversity showed little effect of effort. As such, no residual mask is provided. Figure 82b depicts fish density, and, like the diversity map, is based on an interpolation of total density (individuals per area swept (km^2)) within each 5 minute grid cell. The top 20% of this estimate is bounded by a thin black line. Figures 82a and 82b were clipped using the standard error estimates for the respective interpolated surfaces (access these data on the CD-ROM). This was done to avoid unsupported extrapolation into poorly sampled areas. Figure 82c depicts the top 20% for diversity and density, and the overlap between the two.

DATA SOURCES

Species diversity was calculated using NMFS shelf and slope trawl data collected at depths between 50-1280 meters, between June and November, every third year from 1977-2001. For details on trawl methods see Lauth (2001), Shaw et al. (2000), Turk et al. (2001), and Williams and Ralston (2002).

METHODS

See "Data and Analysis" section.

RESULTS AND DISCUSSION

Diversity. Interpretation of the interpolated maps of fish diversity is hindered by the lack of available data west of the sanctuary boundaries and the high spatial variability within the data. Despite these limitations, three hot spots (top 20%) of fish diversity are apparent: The northernmost hot spot is centered on Cordell Bank within the northwestern corner of the Cordell Bank NMS, and extends northward along the continental slope outside of sanctuary boundaries to Point Arena. Its northern and western extent cannot be determined with the available trawl data as sampling stopped along the edge of high predicted diversity. Extrapolation to the north and west of this area indicates that high diversity may continue beyond the available data. A second area of high diversity is centered at the boundary between the Gulf of the Farallones NMS and the Monterey Bay NMS. The area extends in a southeasterly direction past Point Año Nuevo and ends off northern Monterey Bay. The southernmost hot spot is located between Point Sur and Lopez Point and covers the inshore portions of Sur and Lucia Canyons. Portions of this last hot spot, however, were poorly sampled. There is some evidence of an additional hot spot in the shallow waters (<200m) straddling the southern boundary of the Monterey Bay NMS and extending into Morro Bay.

Overall, a total of 27,000 square kilometers were modeled for fish diversity. Of that, roughly 5,400 square kilometers were classified as a hot spot (top 20th percentile of estimated diversity). Approximately 53% of the entire modeled surface fell inside the boundaries of the 3 National Marine Sanctuaries, with 67% (3,675 km^2) of the hot spot contained within the sanctuaries. Much of the remaining 33% of high diversity extends along the shelf break north of the Cordell Bank NMS to Point Arena.

Density. Interpretation of the fish density maps suffers from the same problems (i.e. lack of data to the west of sanctuary boundaries and high spatial variability) as those encountered for diversity. In addition, densities tend to emphasize the distribution of common numerically dominant species. High density areas of the map can be divided into four major hot spots (top 20%). One hot spot occurs on and to the southeast of Cordell Bank. A second hot spot is found off of Point Reyes. The largest density hot spot covers a large portion of the shelf to the north of Monterey Canyon, the entire area of Monterey Bay, and near shore waters south to Point Sur. Although portions of this hot spot are found over Monterey Canyon, this fact should be incorporated with caution since the deep canyon waters themselves were not sampled. The fourth hot spot is found to the south of Monterey Bay NMS and covers a substantial area of the shelf from Point Estero to Point Sal. This final hot spot is the largest region of high fish density within the mapped area that falls outside of Sanctuary boundaries and overlaps with a much smaller fish diversity hot spot to the north.

A total of 27,000 square kilometers were modeled for fish density, with approximately 5,200 square kilometers classified in this analysis as a hot spot. Approximately 54% of the entire modeled surface fell inside the boundaries of the three National Marine Sanctuaries; however, 76% (4,041 km^2) of the hot spot was contained within the sanctuary boundaries.

Summary. Patterns in both fish diversity and density appear in many cases to be linked to known oceanographic features already mentioned in previous sections. For example, the northernmost diversity hot spot, and some parts of the density hot spot, straddle the shelf break, an area known to concentrate a variety of marine fauna (Kim, 2000; Adams et al., 1995; Yoklavich et al., 2000). The quickly changing depths of the shelf break and slope may also increase diversity by allowing fish with overlapping bathymetric preferences to coexist. Both diversity and density also appear high near well known upwelling regions, including Point Sur, near Point Año Nuevo, and near Cordell Bank. Although the majority of the fish diversity and density hot spots fall within sanctuary boundaries, this fact should be interpreted with caution since the sanctuary area represents approximately half of the mapped region for both of these variables. Areas of high diversity and density outside of the sanctuary boundaries exist to the north and south. Diversity and density to the west of sanctuary boundaries cannot be adequately assessed with the available data.

Section 3: INTEGRATION OF ANALYSES

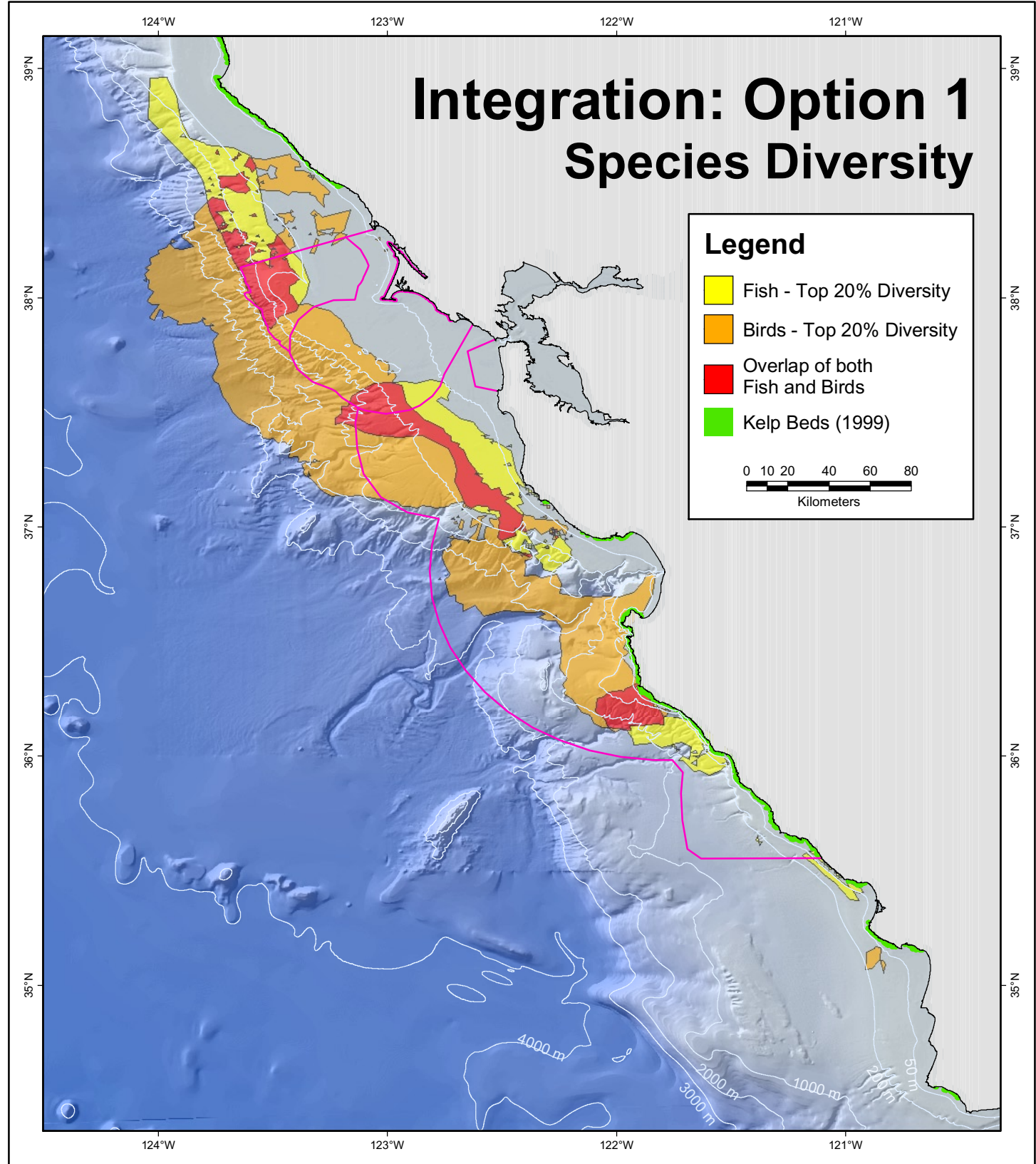


Figure 83. Integration option 1, diversity hot spots (top 20%) for fish and marine birds. Coastal kelp bed areas are also shown.

ABOUT THIS MAP

Figure 83 shows the overlap of diversity hot spots for birds and fishes. As described previously, hot spots were defined as the top 20% of diversity estimated through the spatial modeling process (kriging). Also shown is the most recent estimated distribution of kelp beds within the study area. Although no specific analysis of biodiversity was done for kelp communities, it is well documented that these habitats support a rich and diverse faunal assemblage (Abbott and Hollenberg, 1976; VanWagenen, 2001; McLean, 1962; Foster and Schiel, 1985; Harrold et al., 1988; Thorson 1950; Randall 1965; Dayton 1984; Dean et al., 1984; Ebeling et al., 1985; Harrold and Reed, 1985; Miller and Geibel 1973; King and DeVogelaere, 2000; Van Blaricom and Estes, 1988). Because of this, we have chosen to include kelp distributions in all of the integrated hot spot maps. The kelp distributions depicted here represent only a "snapshot" view of a highly dynamic feature.

DATA SOURCES

Species diversity for fishes was estimated using NMFS shelf and slope trawls data collected at depths between 50-1280 meters, between June and November, every third year from 1977-2001. For details on trawl methods see Lauth (2001), Shaw et al. (2000), Turk et al. (2001), and Williams and Ralston (2002). Species diversity for birds was estimated using data provided by R.G. Ford Consulting and H.T. Harvey and Associates. 1999 kelp distribution data were provided by California Department of Fish and Game.

METHODS

See "Data and Analysis" section.

RESULTS AND DISCUSSION

All three regions of high fish diversity show some overlap with the regions of high bird diversity. An interesting result of this analysis is that all regions of overlap occur near well known upwelling centers (Huyer and Kosro, 1987; Brink and Cowles, 1991; Kelly, 1985; Breaker and Mooers, 1986; Breaker and Gilliland, 1981; Tracy, 1990; Schwing et al., 1991; Breaker and Broenkow, 1994; Rosenfeld et al., 1994); including the area surrounding Cordell Bank, the area south of the Farallones (off point Año Nuevo), and directly adjacent to point Sur. The northernmost fish diversity hot spot overlaps the marine bird diversity hot spot from Cordell Bank north to approximately midway between Bodega Head and Point Arena. The seaward half of the central fish diversity hot spot overlaps with the area of high marine bird diversity within the Gulf of the Farallones NMS and the Monterey Bay NMS. The northern half of the southernmost fish hot spot overlaps the southern tip of the marine bird hot spot. There is a small por-

tion of the Northern overlap of diversity that continues along the slope for 40-50 km beyond the northern boundary of Cordell Bank National Marine Sanctuary.

Overlap in diversity hot spots occurs in both slope and shelf waters. The northernmost hot spot is clearly associated with the slope. The southernmost hot spot is also found in an area of rapidly changing bathymetry off of Point Sur. A large portion of the central diversity hot spot, however, occurs over primarily soft bottom shelf regions. The ecological linkages report (see CD-ROM) cites a considerable volume of literature that describes slope communities as diverse, with well documented trophic interactions between birds and fishes. The authors report that spatial and temporal distribution of plankton is thought to affect the distributions of many fishes and marine birds. In particular, marine birds aggregate in regions with extremely high plankton density, such as Cordell Bank, the Gulf of the Farallones, and parts of Monterey Submarine Canyon (Croll et al., in press). Each of these areas were identified in this analysis as being biodiverse. Furthermore, squid, a primary food source for numerous fishes and birds, concentrate in areas of high plankton productivity (Mais, 1972; Roper and Young, 1975; Anderson, 1977; Pearcy et al., 1977; Anderson and Morel, 1978; Cailliet et al., 1979), where they consume euphausiids and copepods (Karpov and Cailliet, 1979; Chen et al., 1996). This provides further evidence that trophic setting might be partially responsible for the expression of high diversity in areas of upwelling.

Summary

- 1) Diversity overlap between birds and fishes appear to be correlated to known centers of coastal upwelling.
- 2) Overlap occurs in slope and shelf waters.
- 3) Much of the expression of high diversity may be related to the trophic setting in these areas rather than directly to the physical factors that characterize these areas.

Section 3: INTEGRATION OF ANALYSES

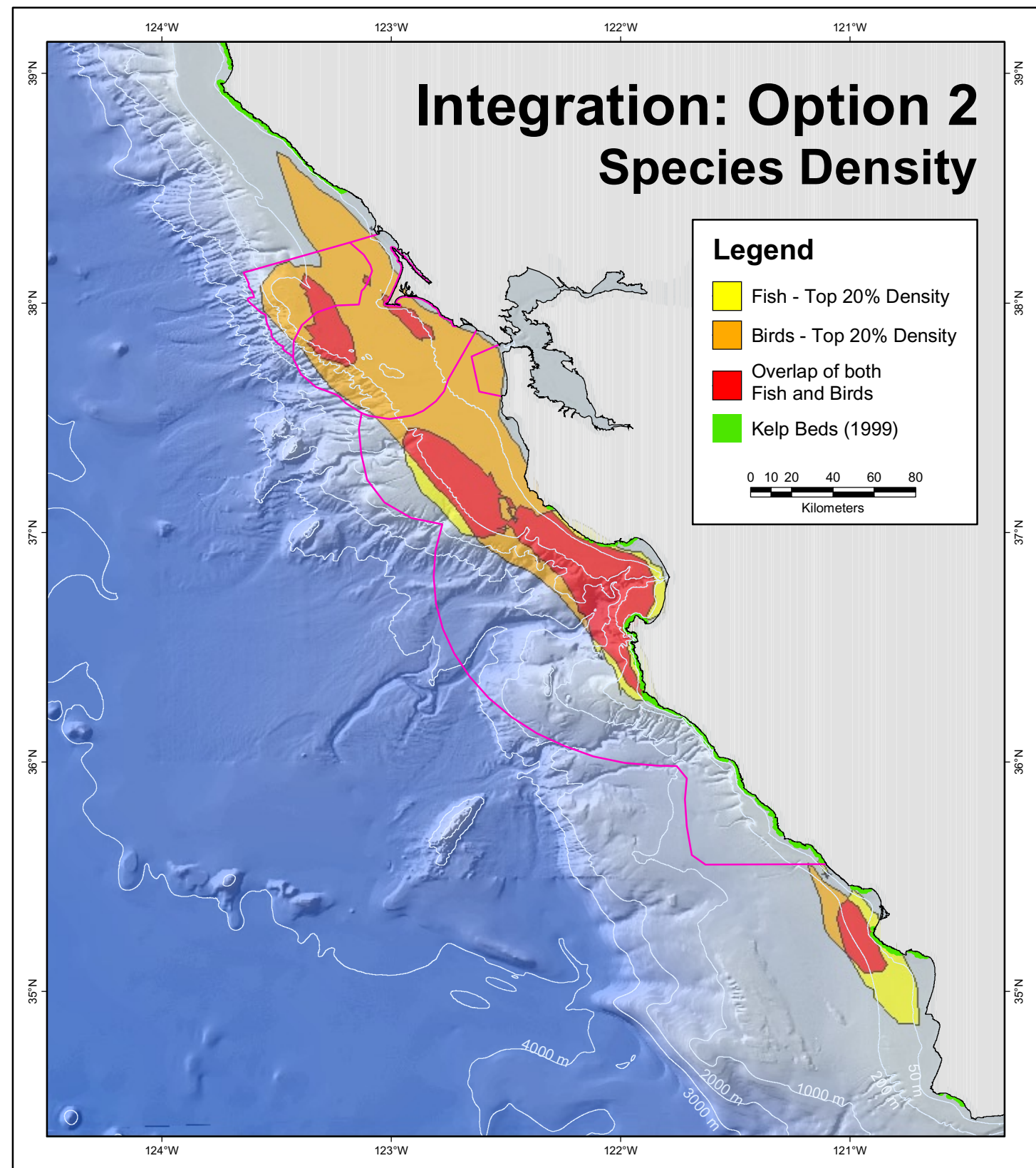


Figure 84. Integration option 2, density hot spots (top 20%) for marine birds and fish. Coastal kelp bed areas are also shown.

ABOUT THIS MAP

Figure 84 shows the overlap of density hot spots for fish and birds. As described previously, hot spots were defined as the top 20% of density estimated through the spatial modeling process. Also shown is the most recent estimated distribution of Kelp beds within the study area. Although no specific analysis of density was done for kelp communities, it is well documented that these habitats support a productive faunal assemblage (Abbott and Hollenberg, 1976; VanWagenen, 2001; McLean, 1962; Foster and Schiel, 1985; Harrold et al., 1988; Thorson, 1950; Randall, 1965; Dayton, 1984; Dean et al., 1984; Ebeling et al., 1985; Harrold and Reed, 1985; Miller and Geibel, 1973; King and DeVogelaere, 2000; Van Blaricom and Estes, 1988). Because of this, we have chosen to include kelp distributions in all of the integrated hot spot maps. The kelp distributions depicted here represent only a "snapshot" view of a highly dynamic feature.

DATA SOURCES

Species density for birds was estimated using data provided by R.G. Ford Consulting and H.T. Harvey and Associates. 1999 Kelp distribution data were provided by California Department of Fish and Game.

METHODS

See "Data and Analysis" section.

RESULTS AND DISCUSSION

Nearly all of the fish density hot spot is coincident with the two areas of high bird density. The distributions for both metrics are generally confined to the shelf (<200m) with the notable exception of Monterey Canyon which appears as a density hot spot for both groups. Although the majority of the hot spots for fish and bird density fall within sanctuary boundaries, it is notable that overlapping hot spots for both groups exist to the south of Monterey Bay NMS. The pattern of marine bird density is dominated by the distributions of the Common Murre (*Uria aalge*) and Sooty Shearwater (*Puffinus griseus*) because they are so abundant. Fish density reflects a somewhat more balanced species composition. Among the most numerically dominant fish species are shortbelly rockfish (*Sebastes jordani*) and Pacific hake (*Merluccius productus*).

Because the modeled distribution of bird density is dominated by two species and all density maps emphasize common species, these maps should be interpreted with caution. While the density interpolation for birds closely approximates what is generally observed in the wild, it is heavily biased towards a few numerically dominant species. This fact may tend to overshadow the density distribution for rare and/or endangered species.

Summary

- 1) There is considerable overlap between areas of high bird and fish density.
- 2) Density maps should be interpreted with caution due to their inherent biases toward numerically dominant species.

Section 3: INTEGRATION OF ANALYSES

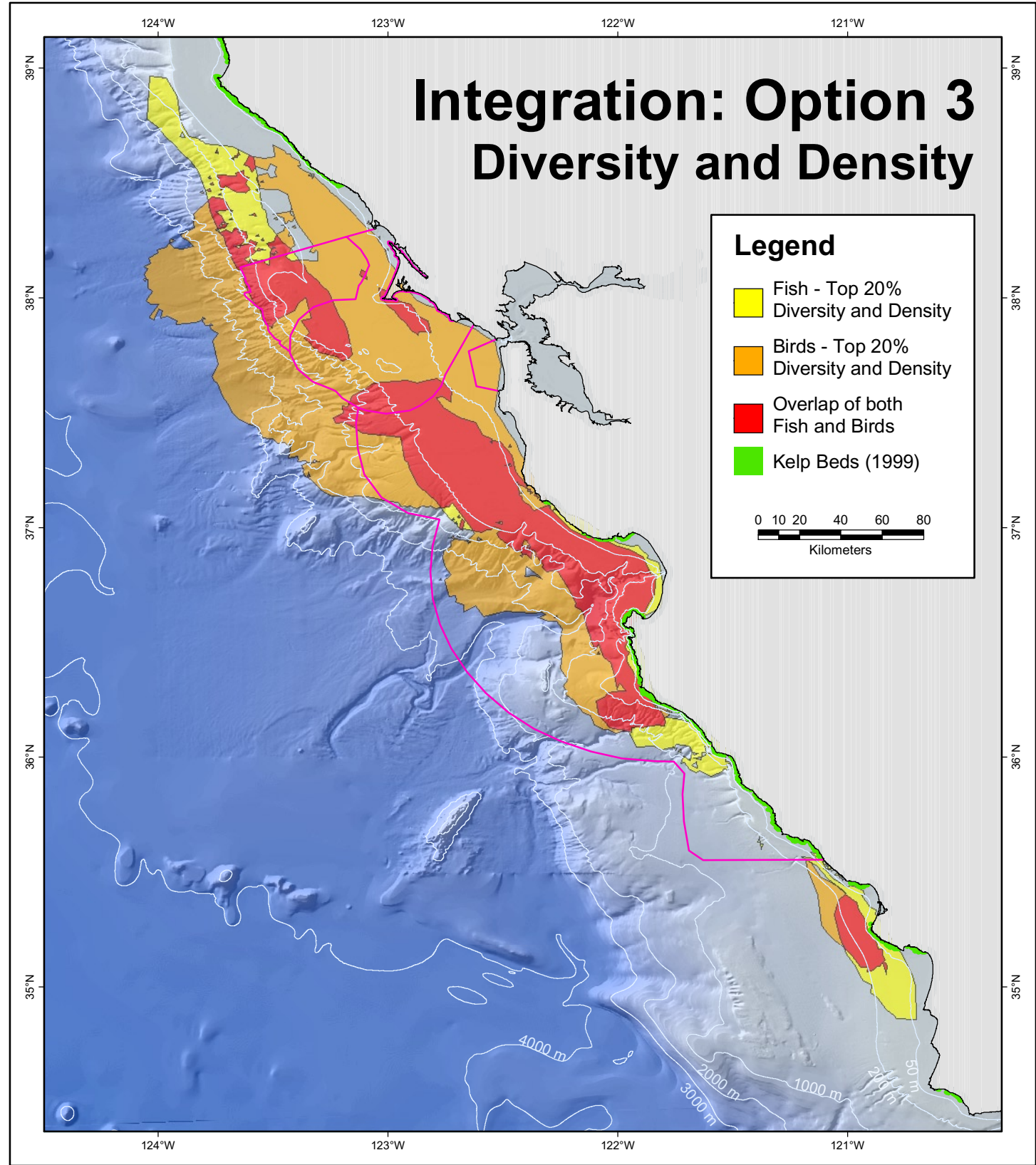


Figure 85. Integration option 3, diversity and density, hot spots (top 20%) for fish and marine birds. Coastal kelp bed areas are also shown.

ABOUT THIS MAP

Figure 85 shows the overlap of options one and two. The top 20% for bird diversity and density were combined, as were the top 20% of fish diversity and density. This is the most inclusive view of marine bird and fish hot spots and the areas they overlap. Also shown is the most recent estimated distribution of kelp beds within the study area. Although no specific analysis of biodiversity was done for kelp communities, it is well documented that these habitats support a rich and diverse faunal assemblage (Abbott and Hollenberg, 1976; VanWagenen, 2001; McLean, 1962; Foster and Schiel, 1985; Harrold et al., 1988; Thorson, 1950; Randall, 1965; Dayton, 1984; Dean et al., 1984; Ebeling et al., 1985; Harrold and Reed, 1985; Miller and Geibel, 1973; King and DeVogelaere, 2000; Van Blaricom and Estes, 1988). Because of this, we have chosen to include kelp distributions in all of the integrated hot spot maps. The kelp distributions depicted here represent only a "snapshot" view of a highly dynamic feature.

DATA SOURCES

Species diversity for fishes was estimated using NMFS shelf and slope trawls data collected at depths between 50-1280 meters, between June and November, during every third year from 1977-2001. For details on trawl methods see Lauth (2001), Shaw et al. (2000), Turk et al. (2001), and Williams and Ralston (2002). Species diversity and density for birds was estimated using data provided by R.G. Ford Consulting and H.T. Harvey and Associates. Kelp distribution data were provided by California Department of Fish and Game.

METHODS

See "Data and Analysis" section.

RESULTS AND DISCUSSION

The majority (71%) of the fish hot spot is coincident with the much larger bird hot spot. The greater area of the bird hot spot (~19,000 km² for birds compared to ~10,000 km² for fish) is due to the greater spatial extent of the bird survey data. Major areas of overlap occur in the following regions:

- 1) from Cordell Bank and the northwest corner of the Gulf of the Farallones NMS north to approximately midway between Bodega Head and Point Arena,
- 2) off Point Reyes,
- 3) shelf waters from the southern boundary of the Gulf of the Farallones NMS south to Point Sur, including Monterey Bay, and
- 4) near shore waters off of Point Buchon.

Although the majority of the regions that were identified as hot spots for fish and birds occur within Sanctuary waters, there are hot spots beyond Sanctuary boundaries to the

north and south. The westward extent of important areas for fish cannot be determined from the available trawl data, and may extend beyond the pictured hot spots. Since Option 3 is simply a combination of Options 1 and 2, all of the concerns and results for those two sections apply here as well.

Summary

- 1) The sanctuary boundaries incorporate much of the highest diversity and highest density areas within the region.
- 2) Many of these biologically important regions coincide with known oceanographic and bathymetric features, such as upwelling regions, areas of high bathymetric variance, and the continental shelf break.
- 3) Regions of high diversity and high density outside of the current sanctuary boundaries exist to the north, across much of the shelf and slope, and to the south, in near-shore waters.
- 4) Uneven sampling effort across the study region and lack of trawl samples to the west of the sanctuary boundaries limit the scope of any integrated biogeographic assessment.
- 5) Known limitations and biases of the two metrics (diversity and density) exist and are discussed elsewhere within this section (Section 3 – Integration).

Section 3: INTEGRATION OF ANALYSES

REFERENCES

Abbott, I. A., and G. J. Hollenberg. 1976. Marine algae of California. Stanford University Press. Stanford, California.

Adams, P. B., J. L. Butler, C. H. Baxter, T. E. Laidig, K. A. Dahlin, and W. W. Wakefield. 1995. Population estimates of Pacific coast groundfishes from video transects and swept area trawls. *Fishery Bulletin* 93: 446-455.

Bakun, A. 1996. Patterns in the Ocean: Ocean processes and marine population dynamics. California Sea Grant College System and the National Oceanic and Atmospheric Administration.

Barber, R. T., and F. P. Chavez. 1983. Biological consequences of El Niño. *Science* 222: 1203-1210.

Bolin, R. I., and D. P. Abbott. 1963. Studies on the marine climate and phytoplankton of the central coast area of California, 1954-1960. California Cooperative Oceanic Fishery Investigations Report 9: 23-45.

Breaker, L. C., and R. P. Gilliland. 1981. A satellite sequence of upwelling along the California coast. *In* Richards, F. A. [Ed.]. Coastal Upwelling. American Geophysical Union. Washington, D. C. Pp. 97-94.

Breaker, L. C., and C. N. K. Mooers. 1986. Oceanic variability off the central California coast. *Progress in Oceanography* 17: 61-135.

Breaker, L. C., and W. W. Broenkow. 1994. The circulation of Monterey Bay and related processes. *Oceanography and Marine Biology* 32: 1-64.

Brink, K. H., and T. J. Cowles. 1991. The coastal transition zone program. *Journal of Geophysical Research* 96: 14637-14647.

Cailliet, G. M., K. A. Karpov, and D. A. Ambrose. 1979. Pelagic assemblages as determined from purse seine and large midwater trawl catches in Monterey Bay and their affinities with the market squid, *Loligo opalescens*. California Cooperative Oceanic Fisheries Investigations Reports 20: 21-30.

Chavez, F. P. 1995. A comparison of ship and satellite chlorophyll from California and Peru. *Journal of Geophysical Research* 100: 24855-24862.

Chavez, F. P. 1996. Forcing and biological impact of onset of the 1992 El Niño in central California. *Geophysical Research Letters* 23: 265-268.

Chen, D. S., G. Van Dykhuizen, J. Hodge, and W. F. Gilly. 1996. Ontogeny of copepod predation in juvenile squid (*Loligo opalescens*). *Biological Bulletin* 190(1): 69-81

Croll, D. A., B. Marinovic, S. Benson, F. P. Chavez, N. Black, R. Ternullo, and B. R. Tershy. *In press*. From wind to whales: trophic links in a coastal upwelling system.

Dayton, P. K., V. Curries, T. Gerrodette, B. Keller, R. Rosenthal, and D. Van Tresca. 1984. Patch dynamics and stability of some southern California kelp communities. *Ecological Monographs* 54: 253-289.

Dean, T. A., S. C. Schroeter, and J. Dixon. 1984. Effects of grazing by two species of sea urchins (*Strongylocentrotus franciscanus* and *Lytechinus anamesus*) on recruitment and survival of two species of kelp (*Macrocystis pyrifera* and *Pterygophora californica*). *Marine Biology* 78: 301-313.

Ebeling, A. W., D. R. Laur, and R. J. Rowley. 1985. Severe storm disturbances and reversal of community structure in a southern California kelp forest. *Marine Biology* 84: 287-294.

Foster, M. S., and D. R. Schiel. 1985. The ecology of giant kelp forests in California: a community profile. U.S. Fish and Wildlife Service Biological Report 85(7.2): 152 pages.

Gotway, C.A, and L. J. Young. 2002. Combining incompatible spatial data. *Journal of the American Statistical Association* 97(458): 632-648.

Guan, W., Chamberlain, R.H., Sabol, B.M. and P.H. Doering. 1999. Mapping submerged aquatic vegetation with GIS in the Caloosahatchee Estuary: Evaluation of different interpolation methods. *Marine Geodesy* 22(2). 69-92.

Harrold, C., and D. C. Reed. 1985. Food availability, sea urchin grazing and kelp forest community structure. *Ecology* 66(4): 1160-1169.

Harrold, C., J. Watanabe, and S. Lisin. 1988. Spatial variation in the structure of kelp forest communities along a wave exposure gradient. *Marine Ecology* 9(2): 131-156.

Huyer, A., and P. M. Kosro. 1987. Mesoscale surveys over the shelf and slope in the upwelling region near Point Arena, California. *Journal of Geophysical Research* 92: 1655-1681.

Kaluzny, S.P., Vega, S.C., Cardoso, T.P., and A.A. Shelly. 1998. S+SpatialStats: Users Manual for Windows and UNIX. MathSoft Inc.

Karpov, K. A., and G. M. Cailliet. 1979. Prey composition of the market squid, *Loligo opalescens* Berry, in relation to depth and location of capture, size of squid, and sex of spawning squid. California Cooperative Oceanic Fisheries Investigations Reports 20: 51-57.

Kelly, K. A. 1985. The influence of wind and topography on the sea surface temperature patterns over the northern California slope. *Journal of Geophysical Research* 90: 11783-11798.

Kim, S. 2000. Patterns in Benthic Communities Within the Sanctuary. Presented at the Monterey Bay National Marine Sanctuary Symposium: Sanctuary Currents 2000: Causes of Ecosystem Change: Natural or Human? March 18, 2000. Coconut Grove, Santa Cruz, CA

King, A., and A. DeVogelaere. 2000. Monterey Bay National Marine Sanctuary final Kelp Management Report. Background, Environmental Setting, and Recommendations. October 3, 2000.

Lauth, R. R. 2001. The 2000 Pacific west coast upper continental slope trawl survey of groundfish resources off Washington, Oregon and California: estimates of distribution, abundance, and length composition. NOAA Tech. Memo. NMFS-AFSC-120. 284 pp.

Levine, Ned. CrimeStat II: A Spatial Statistics Program for the Analysis of Crime Incident Locations (version 2.0). Ned Levine and Associates, Houston, TX, and the National Institute of Justice, Washington, DC. May 2002.

Ludwig, J.A., and J.F. Reynolds. 1988. Statistical ecology: A primer on methods and computing. John Wiley and Sons. New York, NY.

Mais, K. F. 1972. California Department of Fish and Game Sea Survey Cruises 1971. California Cooperative Oceanic Fisheries Investigations Data Reports 21: 1-132.

Malone, T. C. 1971. The relative importance of nannoplankton and netplankton as primary producers in the California Current system. *Fisheries Bulletin* 69: 799-820.

McLean, J. H. 1962. Sublittoral ecology of kelp beds of the open coast area near Carmel, California. *Biological Bulletin* 122: 95-114.

Miller, R. J., and J. J. Geibel. 1973. Summary of blue rockfish and lingcod life histories: a reed ecology study; and giant kelp *Macrocystis pyrifera* experiments in Monterey Bay, California. *Fish and Game Fishery Bulletin* 158: 1-137.

Pearcy, W. G., E. E. Krygier, R. Mesecar, and F. Ramsey. 1977. Vertical distribution and migration of oceanic micronekton off Oregon. *Deep-Sea Research* 24: 223-245.

Randall, J. E. 1965. Grazing effects on sea grasses by herbivorous reef fishes in the West Indies. *Ecology* 46: 255-260.

Roper, C. F. E., and R. E. Young. 1975. Vertical Distribution of Pelagic Cephalopods. Smithsonian Contributions to Zoology 209. 51 pages.

Rosenfeld, L. F. Schwing, N. Garfield, and D. E. Tracy. 1994. Bifurcated flow from an upwelling center: a cold water source for Monterey Bay. *Continental Shelf Research* 14: 931-964.

Ryther, J. H. 1969. Photosynthesis and fish production in the sea. *Science* 166: 72-76.

Schwing, F. B., D. M. Husby, N. Garfield, and D. E. Tracy. 1991. Mesoscale oceanic response to wind events off central California in spring 1989: CTD surveys and AVHRR imagery. California Cooperative Oceanic Fisheries Investigations Reports 32: 47-62.

Shannon, C.E., and W. Weaver. 1949. The mathematical theory of communication. University of Illinois Press, Urbana, IL 125p.

Shaw, F.R., Wilkins, M.E., Weinberg, K.L., Zimmermann, M., and R. R. Lauth. 2000. The 1998 Pacific west coast bottom trawl survey of groundfish resources: estimates of distribution, abundance, and length and age composition. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-114, 138 p.

Thorson, G. 1950. Reproductive and larval ecology of marine bottom invertebrates. *Biological Review* 25: 1-45.

Tracy, D. E. 1990. Source of cold water in Monterey Bay observed by AVHRR satellite imagery. Masters Thesis. Naval Postgraduate School. Annapolis, Maryland. 125 pages.

Turk, T. A., T. Builder, C. W. West, D. J. Kamikawa, J. R. Wallace, R. D. Methot, A. R. Bailey, K. L. Bosley, A. J. Cook, E. L. Fruh, B. H. Hormess, K. Piner, H. R. Sanborn, and W. W. Wakefield. 2001. The 1998 Northwest Fisheries Science Center Pacific west coast upper continental slope trawl survey of groundfish resources off Washington, Oregon, and California: Estimates of distribution, abundance, and length composition. U. S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-50, 122 p.

Section 3: INTEGRATION OF ANALYSES

Van Blaricom, G. R., and J. A. Estes [Eds.]. 1988. The Community Ecology of Sea Otters. Springer-Verlag. Berlin, Germany.

Van Wagenen, R. F. 2001. California Coastal Kelp Resources, Summer 2000. Final Report to the Monterey Bay National Marine Sanctuary.

Williams, E.H. and S. Ralston, Distribution and co-occurrence of rockfishes over trawlable shelf and slope habitats of California and southern Oregon. Fisheries Bulletin, 2002. 100: p. 836-855.

Section 4: DATA SOURCES AND GAPS

INTRODUCTION

This section addresses a secondary objective of the project: the acquisition and assessment of available comprehensive data for the study area and the identification of data gaps in such information. In addition, suggestions are made for prioritizing future research efforts to generate data that would be especially valuable for future biogeographic analyses.

Throughout the project, members of the Biogeography Program contacted numerous academics, scientists, and agency personnel who were likely to have knowledge of data relevant to the study area, compiling a contact list of over 160 people. Additionally, staff consulted the impressive compendium of studies compiled by Monterey Bay Sanctuary staff for their Sanctuary Integrated Monitoring Network (SIMoN) program, which provides a “blueprint for a comprehensive, integrated monitoring network to detect natural and human induced changes to the Monterey Bay National Marine Sanctuary and its resources” (<http://montereybay.noaa.gov/>). Through extensive consultation with contacts, approximately 62 data sets were investigated for incorporation into this study. Data sets were considered in terms of sampling objective, the extent of their spatial and temporal coverage, the existing format and ability to be converted into a GIS layer, the utility of the data compared to the work involved in its incorporation into the project, and whether or not the Biogeography Program was granted access to the data. In general, team members acquired only accessible data sets that had broad spatial extents covering a significant portion of the study area, a large number of samples that could be georeferenced, and high confidence in data quality.

Data sets that met the above criteria were requested and obtained if possible. Once in-house, data were further evaluated in how well they served the objectives of the study, and the most useful data were synthesized into a working GIS library. This involved conversion into GIS format, standardization of geographic projection, and when possible, the aggregation of smaller data sets into a master data layer.

Table 27. Matrix of data sets and their associated characteristics that were used or referenced in the biogeographic assessment.

Data Set	Target Info.	Source Org and/or PI	Dates	Samples	Depth Range	Strengths of Data for Biogeographic Assessment	Constraints of Data for Biogeographic Assessment
Triennial Shelf Trawl Data	Fish, Invertebrates	NMFS (Alaska & Northwest FSC)	1977-1998 every 3 years, June-Aug only	n=994	55-500m	Long time-series, wide spatial extent, fairly good depth range, abandoned trawl areas suggest areas of high rugosity	Sampling only in summer season, some trawls suspected of being off-bottom, rocky areas undersampled due to threat of gear damage.
Slope Trawl Data	Fish, Invertebrates	NMFS	1991, 1997, 1999, 2000, 2001, July-Nov only	n=454	190-1280m	10+ years of data, wide spatial extent, good depth range	Sampling for only 5 months (July-Nov.); identification of common inverts only
NMFS Midwater Trawl Data	Rockfish juveniles	NMFS / SWFSC	1986-2001, May-June only	n=1548	6-32m mean=26m	1500+ tows	Sampling only in May & June, along transects, targets juv. rockfish
Recreational Fish Data	Rockfish	CDF&G	1987-1998, continuous	n=4357	2-360 fm (3-650 m)	provides information about nearshore areas, wide range of depths.	No effort data (presence/absence only), effort targets Rockfish only
Laidig Data	Kelp-Associated Species	Tom Laidig/ NMFS	1983-1995 (Sonoma) year-round but sparse, 1984, 1997, 2001 (Monterey) May-Oct only	n=43 surveys	to max extent of scuba or kelp (<130 ft.)	provides year-round look at kelp in Sonoma 1983-95, quick look at Monterey in 84, 97, 2001; differentiates juveniles and adults.	Sampling is sparse, presence/absence data only, very limited spatial extent
Commercial Fishing Data	Commercially Valuable Fishes	CDF&G	1988-2000, year-round	n=117,176 (records grouped by species, not trip or boat)	shoreline to 4810m	All gear types, data can be sorted by gear, long time series.	Variable reliability re: locations of fishing, summarized to 10-minute grids (large scale), fisheries-dependent, can't sort by boat or trip/effort
Sediment	Substrate Composition	Greene et. al., National Sea Grant College Project	sampling dates unknown, received 12/2002	unknown number	shoreline to ~3500m	5 categories, provides the most comprehensive view of benthic substrates for the study area; in some places very detailed, high resolution; Original data consisted of seismic-reflection profiles and sediment/rock sample data collected by California Division of Mines and Geology, USGS, and California Coastal Commission. New data include multibeam data from MBARI, and Center for Habitat Studies at Moss Landing Marine Laboratories	Based on surface extrapolation of point data, most of the map is low resolution 1:250,000.
Bathymetry-200m	Depth, Topography	CDF&G	unknown	unknown	shoreline to 4810m	best available at the start of the project	Medium resolution
Bathymetry-30m	Depth, Topography	NOAA / NGDC & MBARI	unknown	unknown	shoreline to 4810m	provides higher resolution which increases ability to identify smaller areas of high bathymetric variance, ie. pinnacles and drop-offs	Better resolution, late availability for this project
Kelp Data	Kelp Location	CDF&G	1989, 1999	many, polygon data	surface	Polygons generated from aerial photos provide literal 'snapshot' of kelp along long stretch of coast.	Changes since 1999, missing sections, doesn't differentiate species
Sea Surface Temperature	Sea Surface Temperature	NOAA / Coastwatch	monthly composites	satellite data	surface	Monthly composites available for years 1992 - current.	Monthly composites will smooth out important temporal fluctuations, ie. short upwelling and relaxation events; corrected for best surface.
MMS High Altitude Aerial Surveys	Cetaceans & turtles	Dohl, Minerals Management Service (MMS)	1980-1983, in all three ocean seasons	1,057 cells visited; 76,888km of trackline; 10,014 cell-study-day visits	surface survey of the shelf, slope and deep ocean beyond	Relatively large spatial coverage; cost-effective, year-round synoptic surveys for cetaceans over the shelf and slope.	Data from early 1980s may not represent current status and distribution of species; high altitude surveys may not provide good characterization of smaller, less visible species.
MMS Low Altitude Aerial Surveys	Marine Birds and Mammals	Bonnell-PI for mammals, Briggs-PI for birds; MMS	1980-1983, in all three ocean seasons	870 cells visited; 70,114km of trackline; 9,306 cell-study-day visits	surface survey of the shelf, slope and deep ocean beyond	Relatively large spatial coverage; cost-effective, year-round synoptic surveys for species over the shelf and slope.	Data from early 1980s may not represent current status and distribution of species; low altitude surveys may not provide good characterization of rare cetacean species.
EPOCS Shipboard Surveys	Marine Birds and Mammals	Ainley	1984-1994, in all three ocean seasons	76 cells visited; 1,033km of trackline; 77 cell-study-day visits	surface survey of the deep ocean	Includes outer Calif Current surveys; better species sightability on a ship than an airplane.	Spatial coverage is not as robust as with the aerial surveys, but sightability for some species is better.

Within this library of data, some sets emerged as primary data sources, while others contributed to the project in terms of providing contextual information, reference or validation.

The data sets that ultimately proved most useful in this undertaking are summarized in Table 27 below, which provides information about the source of the data, target information, dates of collection, number of samples, and depth range when available. Additionally, comments about the general strengths and constraints of the data sets in *the context of this analysis* are noted in separate columns. Full citation information for each data set is provided in the list of references that appears at the end of each section utilizing the data.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE ACTIVITIES

During the course of this project, Biogeography Program staff gained a unique familiarity with the data available and the data necessary to undertake the analysis. This position enables project team members to make observations about the types of data that, if acquired, could improve the biogeographic assessment in the future. Some of the data sets may exist, but in a format that could not, in their current state, be incorporated into the project. For example, historical benthic infauna data exists, but has not yet been converted to digital format or updated to reflect current taxonomy. Several important data sets do not, to our knowledge, exist at all or at the necessary spatial scale, but should be considered priorities for future analytical efforts. They appear in the following list.

•**Resolution.** Finer thematic and spatial resolution on the substrate and bathymetric maps will be highly advantageous to the analyses based on Habitat Suitability Modeling. Improving the resolution for the bathymetry map will help identify more small areas of high relief, such as rocky pinnacles, that are known to be important habitat for some species.

•**Spatial Data for Additional Species.** Because of sampling limitations (i.e. mesh or hook size) or a lack of published life history information, some ecologically important species are not represented in this study. More information

Section 4: DATA SOURCES AND GAPS

should be collected on these species through other means. One example is the pygmy rockfish (*Sebastes wilsoni*), a small but abundant species, that does not show up in any of the fisheries-dependent data sets. *S. wilsoni* can be surveyed via submersible, as documented in various studies (Yoklavich et al., 2002; Yoklavich et al., 2000; Hixon et al., 1991). Other species of interest include white shark, pelagic fishes, intertidal species, krill, marine birds, marine mammals and sea turtles.

•**Survey Methods.** Sampling fish communities using a consistent sampling method over all substrate/habitat types, based on stratified random sampling. Multiple survey methods should be employed to ensure representation of important fish species that are not susceptible to current sampling methods.

•**Sampling Strategies.** Sampling strategies should be tailored to include more life history stages of fish, especially larval stages.

•**Sampling Strategy.** Sampling should also be better spread spatially and temporally to:

•*Reduce Effort Disparity. Increased sampling in certain areas would help equalize the distribution of sampling effort across the study area. Some analyses were confounded by the wide range of sampling effort.*

•*Target Important and Under-Sampled Areas. Increasing sampling in important areas that are currently under sampled (e.g. the entire near-shore region and the slope area west of Cordell Bank) or in areas of particular management interest (e.g. boundary regions) would help to better characterize these areas. The techniques used in the integration section can accommodate preferential (i.e. non-random) sampling in areas of interest.*

•**Describing Effort.** Increase consistency in recording effort-related parameters for fisheries trawls (e.g. recording start and end coordinates of trawls) and naturalists' surveys.

•**Expert Knowledge.** Incorporate additional expert knowledge and data from the fishing community, naturalists (e.g. Monterey Bay Whale Watch cruise data), and recognized experts, especially for areas and time periods where there is little or no data.

•**Data Compatibility.** Achieve consensus on the best way to merge aerial and ship-based survey data for birds and mammals.

•**Location Verification for Fisheries Data.** Verification of the spatial reporting from commercial fishing logbooks would enable the full incorporation of this valuable data source.

•**Abandoned Trawls.** Incorporation of NMFS's study of abandoned trawl locations from the Triennial Surveys. Such information indicates areas that are difficult to trawl or 'untrawlable' due to the fact that the nets repeatedly became caught or torn during trawl attempts. These locations may indicate areas with rocky substrates and high rugosity, which, though still targeted by hook and line and recreational fishers, are generally protected from trawl fishing methods.

•**Oceanographic Influences.** Incorporation of more oceanographic features and parameters into the analyses, especially for birds and mammals. Ephemeral features such as currents, the San Francisco plume, and sources of upwelling could be represented in probability maps or by aggregating empirical data by various temporal categories (e.g. by week, event, month, season, warm/cold period, etc.).

•**Kelp Surveys.** Increased frequency of surveys to better monitor changes in kelp distribution; differentiation between kelp species.

•**Life History/Trophic Linkages.** Expanded knowledge of life history characteristics, habitat affinities, distribution and abundance of pelagic prey species, and links between predators and prey species (i.e. hake, krill, and plankton) will help describe distributional changes based on trophic linkages and foraging behavior.

•**Life History/Spawning Areas.** Incorporation of known spawning areas will help identify important areas and seasonal changes in distribution for fish.

•**Data QA/QC.** Data quality assurance would allow the incorporation of some existing data sets that were discarded due to inconsistencies in species coding (e.g. the fisheries data set targeting salmon), taxonomic changes (e.g. benthic infauna data) or other reasons.

•**Expansion of Scope.** The scope of this analysis could be broadened to include adjacent habitats. For example, the interaction between marine and estuarine habitats could possibly be addressed using network analysis of energy flows between ecosystems. As part of the Estuarine Living Marine Resources (ELMR) series, a 2-volume comprehensive data base on the distribution of estuarine fishes and invertebrates in West Coast estuaries was completed in 1990-91 (Emmett, et al., 1991; Monaco, et al., 1990; Nelson and Monaco, 2000). If updated,

the resource could be used to couple estuarine, coastal and marine ecosystems.

•**Wider Regional Context.** Expansion of the scope of the study to include the biogeography of the entire west coast of North America to better understand how the north/central California region fits into the wider biogeographic context. A precedent exists in the West Coast Atlas produced by NOAA's SEA Division. Such a document could serve as a blueprint for defining species distributions along the west coast of the continental U.S. (SAB/NWAFS 1988, SAB 1990).

REFERENCES

Emmett, R.L., S.L. Stone, S.A. Hinton, and M.E. Monaco. 1991. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume II: Species life history summaries. ELMR Rep. No. 8. NOAA/NOS/Strategic Environmental Assessments Division. Rockville, MD. 329 pp.

Hixon, M.A., B.N. Tissot, and W.G. Pearcy. 1991. Fish Assemblages of Rocky Banks of the Pacific Northwest [Coquille, Daisy, and Heceta Banks]. A final report by the Department of Zoology and College of Oceanography of Oregon State University for the U.S. Department of the Interior, Minerals Management Service Pacific OCS Office. Contract No. 14-12-0001-30445. Camarillo, CA. 410 pp.

Monaco, M.E., R.L. Emmett, D.M. Nelson, and S.A. Hinton. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: Data summaries. ELMR Rep. No. 4. NOAA/NOS/Strategic Environmental Assessments Division. Silver Spring, MD. 332 pp.

Nelson, D.M, and M.E. Monaco. 2000. National overview and evolution of NOAA's Estuarine Living Marine Resources (ELMR) Program. NOAA Tech. Memo. NOS NCCOS CCMA 144. Silver Spring, MD. 60 pp.

SAB (Strategic Assessment Branch). 1990. NOAA's west coast of North America data atlas: Invertebrate and fish volume. National Oceanic and Atmospheric Administration. Rockville, MD. 111pp.

SABNAFC (Strategic Assessment Branch, and Northwest and Alaska Fisheries Center). 1988. West coast of North America strategic assessment: data atlas: Marine mammal volume. National Oceanic and Atmospheric Administration. Rockville, MD. 33 pp.

Yoklavich, M.M., G.M. Caillet, R.N. Lea, H.G. Greene, R.M. Starr, J. de Marignac, and J. Field. 2002. Deepwater habitat and fish resources associated with a marine reserve: implications for marine fisheries in marine ecological reserves research program research results. 1996-2001. California College Sea Grant Program CD-ROM. La Jolla, CA. 63 pp.

Yoklavich, M.M., H.G. Greene, G.M. Caillet, D.E. Sullivan, R.N. Lea, and M.S. Love. 2000. Habitat associations of deep-water rockfishes in a submarine canyon: an example of a natural refuge. Fish Bulletin, U.S., Vol. 98, pp. 625-641.

Section 5: SUMMARY OF BIOGEOGRAPHIC ASSESSMENT

BACKGROUND

The mission of NOAA National Ocean Service's (NOS) National Marine Sanctuary Program (NMSP) is to serve as the trustee for a system of marine protected areas, to conserve, protect, and enhance their biodiversity, ecological integrity, and cultural legacy. To assist in accomplishing this mission, the NMSP has developed a partnership with NOAA's National Centers for Coastal Ocean Science (NCCOS) to conduct biogeographic assessments of living marine resources in all National Marine Sanctuaries to characterize and assess the distribution of marine resources that occur within and adjacent to the sanctuaries. The NMSP and NCCOS's Biogeography Program have developed a five-year plan to implement the assessments across the system of National Marine Sanctuaries (Kendall and Monaco 2003). The biogeographic assessment process as defined in the plan is used to conduct studies that are designed to address research needs and support a wide array of sanctuary management decisions. In general, the priority to implement the biogeographic assessments is based on the need to update sanctuary management plans. Thus, the joint efforts are systematically proceeding to work with each sanctuary to provide assessments of species' distributions and their associated habitats in a region.

Since establishment, many of the sanctuaries have witnessed increased pressure on marine resources from natural and anthropogenic phenomena, including climatic variation and degradation of habitats. In order for the NMSP to increase management capabilities, it is imperative that the spatial and temporal distributions of biota and habitats within sanctuaries be delineated. Biogeography provides a framework to integrate species distributions and life history data with information on the habitats of the region to characterize marine resources in a sanctuary. When the biogeographic data are integrated into a Geographic Information System (GIS), it enables users to visualize species' spatial and temporal distributions and conduct ecological forecasts to assess potential changes in species distributions that may result from a variety of natural and anthropogenic perturbations. In addition, based on specific ecological metrics (e.g., diversity), biologically significant areas can be delineated. This document provides the results of the GIS-based assessment conducted for the National Marine Sanctuaries off north/central California to initiate development of a biogeographic assessment capability for the sanctuaries.

BIOGEOGRAPHIC ASSESSMENT OFF NORTH/CENTRAL CALIFORNIA

The initial biogeographic assessment outlined in the five-year NCCOS/NMSP plan was implemented in the spring of 2001 to conduct a 24-month investigation to assess biogeographic patterns of selected marine species found within and adjacent



to the boundaries of three contiguous West Coast National Marine Sanctuaries. These sanctuaries, Monterey Bay, Gulf of the Farallones, and Cordell Bank, are conducting a joint review to update sanctuary management plans. To support the management plan review process, the Biogeography Program is leading a partnership effort to conduct a robust analytical assessment to define important biological areas and time periods within the region. This document represents the results of the first of two assessment phases. Phase I provides data, analytical results, and descriptions of ecosystems and their linkages; it also identifies data gaps, and suggests future activities to be addressed in Phase II.

Phase I of this effort was a biogeographic assessment of existing data on the distribution and abundance of marine fishes, marine birds, marine mammals and their associated habitats. The study did not attempt to define biogeographic patterns along the entire U.S. West Coast nor in very near-shore environments (e.g., estuaries). Rather, the study area was restricted to the marine area from Point Arena in Mendocino County (38°54'32" N, the northern bound) to Point Sal in northern Santa Barbara County (34°54'05" N, the southern bound). The entire study area and regional maps of the area are depicted in Figures 2-5. This relatively large study area enabled the assessment to extend

beyond the limits of current sanctuary boundaries to place study results in the context of north/central California Coast biogeographic patterns. The biogeographic analyses are based on a synthesis of many data sources that were provided by project partners and contributors. Results of this assessment are being used to assist the NMSP in addressing issues such as evaluating potential modification of sanctuary boundaries and changes in management strategies or administration, based on the principles of biogeography.

The biogeographic assessment was formulated around three closely integrated study components: (1) an *Ecological Linkages Report*, (2) biogeographic analyses, and (3) development of GIS data for incorporation into NMSP's Marine Information System (MarIS). The majority of the results from the assessment are presented as a suite of GIS maps to visually display species' biogeographic patterns across the study area. The body of the document provides examples of the entire suite of digital map products found on the companion CD-ROM and located on the Web at http://biogeo.nos.noaa.gov/products/canms_cd/. The spatial data and additional information, such as digital species distribution maps and additional details on analytical methodologies, are also presented on the CD-ROM.

Ideally, biogeographic assessments utilize significant amounts of data that have been collected over the entire spatial extent of the study area over a long time period. However, such a wealth of data is rarely available. In many instances, little information exists to accurately characterize the study area or associated living marine resources. This paucity of comprehensive data can limit the efficacy of biogeographic assessments, but additional analytical methods can be employed to complement the assessment. In addition to analysis of databases, two additional tasks were used to conduct the assessment. First, a synthesis of existing information was compiled and presented in the *Ecological Linkages Report* to incorporate qualitative information about species, habitats and ecological characterization of marine ecosystems and linkages within the study area. Second, species habitat suitability modeling efforts were conducted for fishes to define potential species' distributions based on known habitat affinities and physiological limitations. The potential species distribution maps are displayed as a series of digital maps found on the CD-ROM.

In addition, a critical component of the assessment process was the extensive effort to have the data, analytical approaches, and results peer reviewed. Initial results from the suite of biogeographic analyses were presented to experts familiar with the marine ecosystem off north/central California, as well as to the originators of the data sources, in an attempt to improve the analyses. The role of expert review and input was considerable, and the contributions made by experts have significantly enhanced the assessment. In June 2002, project team members traveled to Seattle, WA and Santa Cruz, CA to discuss and present the results of the Interim Product to West Coast experts (NOAA, 2002). Suggestions were incorporated and a Web site was created to further disseminate analytical products prior to an additional series of meetings. The final suite of review meetings was held in October 2002 in San Francisco and Monterey, CA and in Seattle, WA. At that time, NOS staff invited members of the scientific community to review the preliminary results of the biogeographic analyses. Comments from the October meetings were compiled and reviewed by project personnel, who either incorporated the experts' suggestions or provided explanations as to why they did not. Thus, the integration of the synthesis of ecological linkage information, statistical analyses of existing databases, species habitat suitability modeling, and peer review, resulted in this biogeographic assessment product.

ECOLOGICAL LINKAGES REPORT

Section 1 of the document presents a synopsis of the *Ecological Linkages Report* and provides the context to understand overall biogeographic product results, relative to the ecosystems along the California Coast. The bulk of the report describes ecosystems in the region, key species associated with these

Section 5: SUMMARY OF BIOGEOGRAPHIC ASSESSMENT

ecosystems, and linkages between and among them. In addition, the report presents latitudinal range distributions of species groups, including algae, invertebrates, fish, marine birds and marine mammals. These maps provide an overview of marine species' distributions and biogeographic transitions along the entire west coast of North America. The report also includes important information on ecosystems not easily studied at this large scale via GIS, particularly near-shore communities. The complete report (163 pp.) is on the CD-ROM that accompanies this document (Airamé et al., 2003).

Key West Coast Biogeographic Transitions

- Benthic algae exhibit three major biogeographic transitions at Point Conception, Puget Sound, and the Gulf of Alaska. At all latitudes, the average number of algal species increased with depth from high to low intertidal and subtidal zones.
- Five major transitions occur in distributions of marine invertebrates found in California waters: at Point Conception, Monterey Bay, Puget Sound, and off the coasts of British Columbia and southeastern Alaska. At all latitudes, greater numbers of gastropod species occur in the euphotic zone and on the continental shelf than on the continental slope.
- Pacific coast fishes exhibit two major biogeographic transitions. A biogeographic transition at the Bering Sea is relatively abrupt, corresponding to the northern limit of distributions of over 100 fish species. A broader biogeographic transition occurs along the southern coast of California between Baja California and Point Conception. A few minor shifts in fish species composition occur between Point Conception and the Bering Sea, particularly at Monterey Bay.

BIOGEOGRAPHIC ANALYSES

Section 2 introduces the methods used to conduct the assessment and the results of the biogeographic analyses of selected marine biota off the north/central California coast. This component of the assessment is the cornerstone of the overall biogeographic product to support the NMSP joint management plan review process. The data, analyses, and supporting information are linked using statistical and GIS tools to portray in space and time significant biological areas or "hot spots." The term "hot spot" is defined based on specific criteria or metrics (e.g., species diversity, high species abundance). The vast majority of the analytical results are displayed as a series of maps to identify biologically significant areas in the study area.

There are many different ways to analyze and organize biogeographic information; however, to efficiently support the management plan process, only a limited number of analytical options were invoked. These analyses were selected based

on reviewers' comments on the Interim Product (NOAA 2002), feedback from technical review meetings, and peer review workshops. Thus, a very difficult step in the project was to select and rely on the most appropriate data and analyses to characterize the various components of the marine ecosystem that exist in the study area. The inclusion of the GIS-based products on the companion CD-ROM will enable NOAA staff, advisory councils, and research partners to query data and information relevant for questions and issues that are not specifically addressed in this product.

The first analyses focused on a suite of assemblages analyses to assess the biogeography of fishes and a few macro-invertebrates. Primary data included fisheries-independent data, such as those collected by researchers from the National Marine Fisheries Service (NMFS), and fisheries-dependent data, such as those collected by the California Department of Fish and Game (CDF&G) for recreational fisheries. These data sets, although not spatially or temporally comprehensive, are the most robust data sets that exist for the entire region, and provide considerable information on the distribution of several hundred fish and invertebrate species.

Key Assemblage Analysis Results for Fishes

- Species assemblages and site groups were distinguished through 1-Pearson correlation coefficients with average means clustering technique. Species assemblages from CDF&G recreational, NMFS shelf, and NMFS slope data sets were more resilient than assemblages from the NMFS midwater data set, emphasizing the ephemeral nature of the midwater environment and the smaller midwater data set. The site groups were displayed spatially in a GIS and the average frequency of occurrence of species assemblages was calculated to show the interaction between species assemblages and site groups (i.e., where species assemblages were caught).
- The interaction of the site groups with environmental parameters that were not used to create the groups can be informative about what conditions are affecting species distribution. Depth was highly significant between site groups in all data sets, emphasizing the importance of depth in structuring marine biological communities. Analyses comparing the site groups to other environmental parameters (latitude, sediment size, and bathymetric complexity) were inconclusive, as these parameters often had significant interactions with depth. Latitude was found to have a significant effect only on the midwater assemblages in 1999; there were no discernible latitudinal breaks within the other four assemblages.

- Diversity and richness can be used to delineate fish hot spots. While little variation in diversity and richness were explained by depth ($r^2=0.04$ between both richness and depth and diversity and depth), trawls with high diversity tended to be deeper than trawls with high richness. Trawls with high species richness of rockfish (*Sebastes* and *Sebastolobos*) followed the 200-meter contour, which approximates the break between the shelf and slope.

- Even though richness and diversity are correlated, the maps showed different results. Hot spots in either richness or diversity were identified in all three sanctuaries. In Cordell Bank NMS, there was a group of trawls with high richness near the center of the sanctuary, and another group of trawls with high diversity in the region around the northwest boundary. There was also a large collection of trawls with either high richness or diversity straddling the boundary between Gulf of the Farallones and Monterey Bay NMS. There were lines of high diversity along the 200-meter depth contour north of CBNMS boundary and from Lopez Point south to the southern edge of the study area.

- Starr (1998) addressed the implementation of rockfish no-take areas with two important recommendations. First, in order to properly manage marine ecosystems, fish assemblages must be better understood. Starr stated that once these assemblages are delineated, steps can be taken to ensure that each assemblage receives proper management. This study defined assemblages of fishes for near-shore, shelf, slope and midwater ecosystems. The results of the community metrics and species assemblages are displayed in this document as a series of maps and tables.

- The second recommendation by Starr (1998) was to delineate rectangular no-take areas that cover 20-50 km of the coast and extend west to the edge of the continental shelf. From a biogeographic viewpoint, the results of the spatial analyses coincided with that recommendation, and also identified that deep-slope communities significantly contribute to ground fish biogeographic patterns. Because assemblages follow bathymetry at the scale of this analysis, setting aside an area from the coast through the continental slope could protect all demersal species assemblages identified in this study.

Key Species Habitat Suitability Model Results

Due to limitations in the spatial and temporal extent of data and to complement the assemblage analyses of fishes, species habitat suitability index (HSI) models were developed (Brown et al., 2000). This was done primarily to accommodate the paucity of empirical data in near-shore areas and to target species of special significance to the sanctuaries. An extensive literature review of the life history characteristics of individual

species resulted in information on species' habitat affinities that were converted into quantifiable habitat suitability index values (Monaco et al., 1997). The life history information and associated species habitat suitability index values are found on the CD-ROM. These derived values were input into an equation and used to predict potential species' distributions based on their affinity for the mosaic of bathymetry and bottom habitats found throughout the region. The species habitat suitability models were validated through statistical and spatial analyses, using fishery-independent survey data.

- Bottom substrate and water depth were statistically significant variables used to predict the potential distribution of species based on their habitat affinities.

- Habitat suitability models for an assemblage of rockfish were developed and results indicated that rocky habitats located on the shelf were identified as potential hot spots for adults; whereas mud and sand substrates on the shelf were delineated as potentially important habitats for subadult rockfish.

- Map overlays of all species' HSI models resulted in the delineation of a broad range of important areas that cover the majority of the continental shelf within and adjacent to the three sanctuary boundaries.

Key Marine Bird Analytical Results

The Biogeography Team contracted principal investigators David Ainley and Glenn Ford (of H.T. Harvey and Associates and R.G. Ford Consulting Co.) to work with the NOAA project team to define and assess biogeographic patterns and important areas for marine birds (and mammals) found within the study area. These experts used regression analysis, GIS and over eight spatial data sets to develop over 50 maps that display marine spatial and temporal patterns, and estimated densities and diversity for selected marine birds in the study area. The resulting maps and discussion summarize important locations, time periods, and life history information for marine birds in the study area. Phase II of the assessment may include a technical report on the methods and results summarized in the Phase I map and tabular products.

- In general, the marine birds of the three sanctuaries are dominated in number and biomass by seasonally resident, nonbreeding species, such as sooty shearwater, pink-footed shearwater, northern fulmar and black-legged kittiwake. The richness of the food web is the primary factor that attracts these species to the region.

- Seasonal, interannual and decadal variation of the regional biogeography of marine birds is influenced by the vagaries

Section 5: SUMMARY OF BIOGEOGRAPHIC ASSESSMENT

of marine climate, which is driven by the California Current System and local upwelling centers. Therefore, the biogeographic patterns of marine birds are not static and exhibit a dramatic spatial and temporal variation, both in species composition and species abundance.

- The Gulf of the Farallones, the area lying inside a triangle defined by Point Reyes, the Farallon Islands and Año Nuevo Island, is the most important area for marine birds in California. The reasons are: (1) large and taxonomically diverse, demographically related populations breed at the three afore-mentioned sites; and (2) an unparalleled diversity of habitat (e.g., San Francisco Bay tidal plume, shallow sandy shelf, rocky reefs, submarine peaks, and the upper continental slope) attracts a variety of migrant and seasonally resident species.
- A "halo" of individuals was apparent around important breeding sites, such as the Farallon Islands and Año Nuevo Island. This pattern is the result of breeding individuals searching for food, but going only as far as necessary to provide for their young. The Farallon "halo" for ashly storm-petrel, western gull, common murre, rhinoceros auklet and Cassin's auklet, extends substantially west of the Gulf of the Farallones National Marine Sanctuary.
- The marine birds of the Gulf of the Farallones/Cordell Bank NMS (as defined above) and the birds of the Monterey Bay NMS are associated with different habitat features. The Gulf of the Farallones has islands and a relatively broad shelf, while Monterey Bay has a relatively narrow but sheltered shelf, cut by an immense, deep submarine canyon. The greater oceanic influence and lack of breeding islands in the Monterey Bay NMS drive the marine bird species groups there.

Preliminary Marine Mammal Analytical Results

The Biogeography Team contracted principal investigators David Ainley and Glenn Ford (of H.T. Harvey and Associates and R.G. Ford Consulting Co.) to work with the NOAA project team and local marine mammal experts to identify biogeographic patterns and important areas and time periods for marine mammals occurring in the study area. NOAA/NMFS scientists provided additional marine mammal sightings data along the entire West Coast to aid in analyzing marine mammal biogeographic patterns relative to the study area. The "bird and mammal team" used a GIS to develop a preliminary series of maps that show occurrence patterns and important areas and time periods for 13 marine mammals in the study area. Phase II of this assessment will: incorporate additional data, develop additional marine mammal species and species group maps, and attempt to develop selected community metrics analyses across species and time periods. A technical report on this

work is also planned.

Spatial Patterns. The spatial occurrence of marine mammals relative to large bathymetric features (e.g., shelf, upper slope, lower slope) and discrete physiographic features (e.g., seamounts, banks, canyons, points and islands) varied by species and ocean condition. The occurrence patterns of most marine mammals are strongly linked to the highly variable ocean conditions of the study area, which significantly affect the distribution of prey availability. In Phase II of this work, when the data sets are more spatially and temporally robust, summary analyses will be conducted to identify important areas and time periods across marine mammal groups.

Large Cetaceans. Important areas for the large cetaceans varied by species: the coast and inner shelf were important for the gray whale; the outer shelf, slope, and deep ocean were important for the humpback and blue whales; and many important areas for large cetaceans were identified seaward of the sanctuary boundaries.

Small Cetaceans. Review of the maps indicated that important areas for the relatively abundant small cetaceans were the outer shelf and upper slope, Monterey Canyon, Sur and Lucia Canyons (west and south of the Monterey Bay NMS), Pioneer Canyon (west of the Monterey Bay NMS), Ascension, Cabrillo, Año and Carmel canyons, Cordell Bank (and to the north of the Cordell Bank NMS boundary), and the San Francisco Bay tidal plume area (e.g., harbor porpoise). Smaller cetaceans were also relatively abundant in areas that include canyons, and in locations beyond sanctuary boundaries, but within the study area.

Pinnipeds. Important areas for resident breeders (e.g., harbor seal, Steller sea lion) were inner and outer shelf habitats, and for northern elephant seal, pelagic deep ocean habitats seaward of sanctuary boundaries. Seasonal visitors (e.g., northern fur seals) occurred mostly in slope and deep ocean habitats, seaward of sanctuary boundaries.

Temporal Patterns. The patterns of seasonal occurrence for marine mammals varied by species. In Phase II of this work, when the data sets are more complete, summary spatial and temporal analyses across marine mammal groups will be conducted.

Large Cetaceans. The seasonal occurrence of the larger cetaceans in the study area reflected their migrations. The Davidson Current season was important for the gray whale, a period when this species is migrating either south or north. Several species of the large cetaceans migrate to forage seasonally in the study area, a pattern reflected in the relative

abundance of the humpback and blue whales during the Upwelling and Oceanic seasons.

Small Cetaceans. An important time period for the Pacific white-sided dolphin (the most abundant small cetacean in this study) was the Oceanic season. Important time periods for the other relatively abundant smaller cetaceans (northern right-whale dolphin, Risso's dolphin, Dall's porpoise) could not be determined in this preliminary assessment.

Pinnipeds. The seasonal occurrence of pinnipeds was associated with the breeding cycles of the species. Important time periods for the relatively abundant northern fur seal were winter and early spring (Davidson Current and early Upwelling seasons), which reflected the pelagic offshore distribution along the West Coast during the nonbreeding season. The relatively abundant California sea lion was present year-round in the study area, with densities greater during the Oceanic season (just after breeding) and Davidson Current season (before the breeding season). Elephant seals, Steller sea lions, and harbor seals were present in sanctuary waters year-round in relatively low numbers; and important time periods for these infrequently sighted species were inconclusive due to differences in behavior and low abundance (e.g., at-sea sightings typically consist of single individuals or small groups of two or three, elephant seals are rarely at the surface, and Steller sea lions are a threatened species).

INTEGRATION OF ANALYSES

The integration of analyses across taxa occurs in Section 3. Many possible combinations of the data layers could be integrated for the biogeographic assessment. Because of differences in sampling design, it was not appropriate to combine data from different taxa (e.g. birds and fish) in order to calculate community metrics. Therefore, to minimize confounding results and to focus on the "protection of biodiversity" component of the NMSP mission, diversity and density were calculated separately for each taxon and the resulting patterns were overlayed to identify biologically important areas across species groups. Spatial interpolation methods were applied to survey data to provide a clearer picture of the distribution of diversity and density within the study area. Hot spots were defined as regions in which diversity or density were estimated to be in the top 20% for a particular taxon. These hot spots were mapped for fish and birds individually and then combined to show areas of overlap. These areas of significant biological importance contributed to defining and assessing biogeographic patterns within the study area and are discussed in the context of known oceanographic features and Sanctuary boundaries. All of the conclusions listed below should be considered with an understanding of the inherent limitations of the available data and the approaches used to analyze it. A detailed discussion of

these concerns is presented in Section 3.

Key Findings of Integration of Analyses

Fish Diversity (Trawl data). Three major areas of relatively high fish diversity (i.e., hot spots) were delineated, as noted below.

- The northernmost hot spot is centered on Cordell Bank, within the northwestern corner of the Cordell Bank NMS, and extends northward along the continental slope to Point Arena.
- The central hot spot is centered at the boundary between the Gulf of the Farallones NMS and the Monterey Bay NMS. The area extends in a southeasterly direction past Point Año Nuevo and ends offshore, north of Monterey Bay.
- The southernmost hot spot is located between Point Sur and Lopez Point and covers the inshore portions of Sur and Lucia Canyons. Portions of this last hot spot, however, were poorly sampled. There is evidence of an additional hot spot straddling the southern boundary of the Monterey Bay NMS.

Marine Bird Diversity

- The interpolated maps of marine bird diversity show one continuous area of high diversity along the continental slope, and, to a lesser extent, along the shelf between Point Arena and Point Sur. Within this area, diversity appears to be highest on, and seaward of, the Farallon Escarpment, in the northwestern corner of the Monterey Bay NMS (Pioneer Canyon), and in the marine region between Point Lobos and Point Sur.
- The Farallon Escarpment in particular received a disproportionate amount of survey effort. The high estimated marine bird diversity for the Farallon Escarpment is, in part, due to high sampling effort.
- A marine bird diversity hot spot was found in the region between Point Lobos and Point Sur. The high residual diversity in this area supports the interpretation that this is a real hot spot and not an artifact of survey effort.

- Marine bird diversity was correlated with survey effort, so some of the "hot spot" diversity areas coinciding with areas of high survey effort may, in part, be influenced by high levels of effort. However, the general patterns of marine bird diversity are robust, and were largely unchanged by methods designed to correct for effort.

Overlap of Marine Bird and Fish (Trawl) Diversity

- Fish diversity shows overlap with the areas of high bird diversity. The northernmost fish hot spot overlaps the marine bird hot spot from Cordell Bank north to approximately mid-

Section 5: SUMMARY OF BIOGEOGRAPHIC ASSESSMENT

way between Bodega Head and Point Arena. The seaward half of the central fish hot spot overlaps with the area of high marine bird diversity within the Gulf of the Farallones NMS and the Monterey Bay NMS. The northern half of the southernmost fish hot spot overlaps the southern tip of the marine bird hot spot.

Fish Density (Trawl Data)

Four major hot spots of fish density were found:

- The northernmost hot spot is found on and to the southeast of Cordell Bank.
- A small hot spot is found off of Point Reyes.
- The largest fish density hot spot covers a large portion of the shelf to the north of Monterey Canyon, the entire area of Monterey Bay, and the near shore waters south to Point Sur. Although portions of this hot spot are found over Monterey Canyon, this fact should be interpreted with caution since the deep canyon waters themselves were not sampled.
- The fourth hot spot is found to the south of Monterey Bay NMS and covers a substantial area of the shelf from Point Estero to Point Sal. This final hot spot is the largest region of high fish density within the mapped area that falls outside of Sanctuary boundaries.

Marine Bird Density

- Marine bird density patterns should be interpreted with caution since they largely reflect the distribution of the two numerically dominant species.
- A large region of high (top 20th percentile) marine bird density exists adjacent to and shoreward of the marine bird diversity hot spot. This density hot spot covers most of the shelf waters of all three sanctuaries, from Point Sur in the south to midway between Bodega Head and Point Arena in the north. The density hot spot extends into Monterey Bay.
- An additional density hot spot exists off of Morro Bay to the south of the Monterey Bay NMS.

Overlap of Marine Bird and Fish (Trawl) Density

- Nearly all of the fish density hot spots are coincident with the two areas of high bird density.
- The hot spots for both metrics are generally confined to the shelf (<200m) with the notable exception of Monterey Canyon which appears as a density hot spot for both groups. The deep Canyon, however, was not sampled in the fish trawl surveys.

- Although the majority of the hot spots for fish and bird density fall within sanctuary boundaries, it is notable that overlapping hot spots for both groups exist to the south of Monterey Bay NMS.

Overall Integration Summary

- The current Sanctuary boundaries incorporate much of the highest diversity and highest density areas within the region.
- Many of these biologically important regions coincide with known oceanographic and bathymetric features, such as upwelling regions, areas of high bathymetric variance, and the continental shelf break.
- Regions of high diversity and high density outside of the current sanctuary boundaries exist to the north, across much of the shelf and slope, and to the south, in near-shore waters.
- Uneven sampling effort across the study region and a lack of trawl samples to the west of the Sanctuary boundaries limit the scope of any integrated biogeographic assessment.
- Known limitations and biases of the two metrics (diversity and density) exist and are discussed in greater detail within Section 3.

DATA SOURCES AND GAPS

Recognizing that any analysis is only as good as the data upon which it is based, the project team undertook a qualitative evaluation of the data used in this project and identified relevant data gaps. This information is presented in Section 4: Data Content and Gaps. This section describes the process used to select key databases for analyses and briefly addresses strengths and limitations of each database. This information was used to aid in the interpretation of the biogeographic analyses to minimize confounding of results due to information gaps. Also provided are recommendations for future research activities that would enhance biogeographic assessment products.

PHASE II BIOGEOGRAPHIC ASSESSMENT

Section 6 suggests potential next steps to augment the Phase I analyses. Phase II, however, will not be completely designed until a review of Phase I products has occurred. The NMSP and NCCOS project team members will meet to define the additional suite of activities that will comprise Phase II. Nevertheless, a few priority activities are expected to occur in Phase II, including expanding the analytical products for fishes, marine birds, and marine mammals. Special emphasis will be placed on the biogeographic analyses of marine mammal data,

as that component of the study was not completed in Phase I. The marine mammal analyses are one of the first efforts to assess biogeographic patterns of marine mammals in the study area; thus, additional analyses and peer review are required to complete this component of the study.

Phase II activities may include publishing technical reports and peer-reviewed articles that complement the results of the Phase I assessment, as well as additional analyses to further define biological areas and time periods important to marine fishes, birds, and mammals found throughout the study area.

CD-ROM

A digital version of this document, the *Ecological Linkages Report*, all GIS-compatible files used to conduct the biogeographic analyses, metadata for GIS files, and a complete suite of digital species maps, are found on the CD-ROM located on the back cover of this document.

All appropriate digital data and analytical products are found on the CD-ROM. The products come in several formats, including this document (in .pdf format), map products in a browsable web format (HTML), GIS shapefiles and grids for use with MarIS or ArcView (GIS) software, tables in Excel format (.xls), and descriptive text files. Metadata for each shapefile or grid accompanies each file and appears in .xml format.

To support the NMSP and others in making maximum use of the spatial data generated from this study, along with other products (e.g., economic assessments) that support the joint management plan review, the NMSP is developing a GIS tool, the Marine Resource Information System (MarIS). MarIS has been designed to facilitate the organization, analysis and display of spatial data to support analysis of NMSP management questions and issues within and across sanctuaries. All applicable spatial data will be integrated into MarIS to enable NMSP staff and partners to conduct additional biogeographic analyses in Phase II.

CONCLUDING COMMENTS

This spatially explicit assessment provides a robust set of analytical results and GIS data to strengthen the sustainable management of marine resources within and adjacent to the sanctuaries. A primary use of the biogeographic assessment will be to support the NMSP as it continues to conduct the joint management plan review for the three sanctuaries. In addition, the Biogeography Program will assist the NMSP in further analyses and presentations of the data and analytical results to address specific research and management questions. This Phase I product provides the foundation to continue the development of a biogeographic assessment capability to

support the Cordell Bank, Gulf of the Farallones, and Monterey Bay National Marine Sanctuaries.

REFERENCES

Airamé, S., S. Gaines, and C. Caldow. 2003. Ecological Linkages: Marine and estuarine ecosystems of central and northern California. NOAA, National Ocean Service. Silver Spring, MD. 163 pp.

Brown, S.K., K.R. Buja, S.H. Jury, M.E. Monaco, and A. Banner. 2000. Habitat suitability index models for eight fish and invertebrate species in Casco and Sheepscot Bays, Maine. North American Journal of Fisheries Management, Vol. 20, pp. 408-435. 28 pp.

Kendall, M.S. and M.E. Monaco. 2003. Biogeography of the National Marine Sanctuaries: A partnership between the NOS Biogeography Program and the National Marine Sanctuary Program. NOAA. Silver Spring, MD. 8 pp.

Monaco, M.E. and J.D. Christensen. 1997. Biogeography Program: Coupling species distributions and habitat. In: Changing oceans and changing fisheries: Environmental data for fisheries research and management. G.W. Boehlert and J.D. Schumacher (Eds.). National Marine Fisheries Service Technical Memorandum NOAA-TM-NMFS-SWRSC-239, Pacific Grove, California. 7 pp.

NOAA's National Centers for Coastal Ocean Science and National Marine Sanctuary Program. 2002. Interim Product: A Biogeographic Assessment off North/Central California: To Support the Joint Management Plan Review for Cordell Bank, Gulf of the Farallones and Monterey Bay National Marine Sanctuaries. Silver Spring, MD. 38 pp.

Starr, R.M. 1998. Marine harvest refugia for West Coast rockfish: A workshop. Pacific Grove, California. NOAA-TM-NMFS-SWFSC-255. La Jolla, CA. 14 pp.

Section 6: PHASE II BIOGEOGRAPHIC ASSESSMENT

Phase II of the biogeographic assessment of north/central California to support the research and management needs of Cordell Bank, Gulf of the Farallones, and Monterey Bay National Marine Sanctuaries will build on the information and analytical results presented in Phase I. Phase II, however, will not be completely designed until a review of Phase I products has occurred. Most important, the NMSP and NCCOS project team members will meet to define an additional suite of activities that may comprise Phase II. Nevertheless, a few priority activities are expected to occur in Phase II, including expanding the analytical products for fishes, marine birds, and marine mammals. A special emphasis will be placed on the biogeographic analyses of marine mammal data, as that component of the study was not completed in Phase I. The marine mammal analyses are one of the first efforts to assess biogeographic patterns of mammals in the study area, thus additional analyses and peer review are required to complete this section of the study.

Phase II activities may include publishing technical reports and peer reviewed articles that complement the results of the Phase I assessment and further define areas and time periods important to fishes, marine birds, and marine mammals found throughout the study area. Also, discussions will be held between project partners to determine if additional assessments should be implemented to study near-shore and estuarine ecosystems and associated key species groups such as marine and coastal invertebrates. These ecosystems and species were only qualitatively addressed in the *Ecological Linkages Report* due to data limitations, and time and resource constraints to complete the first phase of the project. In addition, to continue to implement the 5-year Biogeography Program plan developed by NCCOS in consultation with the NMSP, additional habitat and environmental maps under various temporal climate regimes could possibly be addressed to support future biogeographic analyses. For example, climatic regime shifts and associated influences on the distribution of living marine resources may provide additional insight into natural or anthropogenic perturbations on regional biogeographic patterns.

For now, project partners and colleagues are encouraged to provide comments on the information and analytical results provided in this document and on the CD-ROM. Also, please provide suggestions on how best to address Phase II proposed activities and new biogeographic assessment studies that may complement or improve Phase I analyses. For further information or to provide comments on the Phase I product and Phase II activities, please contact:

Dr. Mark E. Monaco, Biogeography Team Leader
NOAA/NCCOS/CCMA
1305 East West Highway, N/SCI1
Silver Spring, MD 20910
p. 301-713-3028 x 160
f. 301-713-4384
mark.monaco@noaa.gov

or

Mr. Charles E. Alexander, National Programs Branch Chief
NOAA/NMSP
1305 East West Highway,
Silver Spring, MD 20910
p. 301-713-3125 x 147
f. 301-713-0404
charles.alexander@noaa.gov

ACKNOWLEDGEMENTS

A project of this magnitude would not have been possible without the cooperation, time, data and effort of numerous people and institutions. We would like to thank everyone who participated in this significant undertaking. The following is a list of those who have contributed to this work.

Sarah Allen
Tara Anderson
Jay Barlow
Lillian Becker
Heather Beeler
Scott Benson
Carol Bernthal
Nancy Black
Laurence Breaker
Joelle Buffa
Tonya Builder
Gregor Cailliet
John Calambokdis
James Caretta
Mark Carr
Harry Carter
Josh Churchman
Elizabeth Clarke
Steve Copps
Natalie Cosentino
Don Croll
Brad Damitz
Chris Essert
Megan Ferguson
Doug Forsell
Fathey Fosmark
Michael Gallagher
Jim Glock
Gary Greene
Denise Greig
Deirdre Hall
Rick Hanks
Michael Harris
Chris Harvey
Jim Harvey
Brian Hatfield
Laird Henkel
Michelle Hester
Tom Hourigan
Ruth Howell
David Hyrenbach
Todd Jacobs
Brian Jarvis
Roxanne Jordan
Mike Kenner
Stacy Kim
Chad King
Howatt King

Jamie Kum
Tom Laidig
Mark Lampinen
Bob Lauth
Bob Leeworthy
Phil Levin
Steve Lonhart
David Lott
Mark Lowry
Gerry McChesney
Huff McGonigal
Nazila Merati
Richard Methot
Pat Morris
Joe Mortenson
Hannah Nevins
Kelly Newton
Jim Nybakken
Jim Oakden
Mike Parker
John Pearce
Brady Phillips
Holly Price
Stephen Ralston
Bob Read
Paul Reilly
Dale Roberts
Nora Rojek
Kaustuv Roy
Mary Jane Schramm
Michelle Staedler
Rick Starr
William Sydeman
Mario Tamburri
Christine Taylor
Julie Thayer
Teresa Turk
W. Breck Tyler
Tiffany Vance
Kerstin Wasson
Mark Wilkins
Deb Wilson-Vandenberg
Lisa Wooninck
Nancy Wright
Levon Yengoyan
Mary Yoklavich
Mark Zimmermann

Federal Government
National Centers for Coastal Ocean Science, National Ocean Service (NOS), NOAA
National Marine Sanctuaries National Program Office, NOS, NOAA
Cordell Bank National Marine Sanctuary Office, NOS, NOAA
Gulf of the Farallones National Marine Sanctuary Office, NOS, NOAA
Monterey Bay National Marine Sanctuary Office, NOS, NOAA
Channel Islands National Marine Sanctuary Office, NOS, NOAA
Special Projects Office, NOS, NOAA
Coastal Services Center, NOS, NOAA
Southwest Fisheries Science Center, National Marine Fisheries Service (NMFS), NOAA
Northwest Fisheries Science Center, NMFS, NOAA
Alaska Fisheries Science Center, NMFS, NOAA
U.S. Geological Survey, Department of Interior
Minerals Management Service, Department of Interior
U.S. Fish and Wildlife Service, Department of Interior
Point Reyes National Seashore, National Park Service, Department of Interior

State/Local Government
California Department of Fish and Game, Marine Region
University of California, Santa Barbara
California State University, Monterey Bay
California State University, Moss Landing Marine Laboratories
San Francisco Public Utilities Commission

Non-Governmental Organizations
Alliance of Communities for Sustainable Fisheries
H.T. Harvey and Associates
R.G. Ford Consulting Company
Monterey Bay Aquarium Research Institute
PRBO Conservation Science
Diablo Canyon Power Plant